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Analysis of Market Factors Associated with Sales of Cut Natural Christmas Trees

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Abstract

A study of the market performance of natural Christmas tree retailers in Winston-Salem, North-Carolina, revealed that success was strongly related to location in active retail shopping areas. Christmas tree retailers in shopping centers or areas high in retail sales sold more trees, received a higher average price, and had fewer trees left unsold than retailers in suburban or residential areas. Market factors that contributed to the success of these lots were better merchandising practices, better quality trees, ample parking space, high customer traffic, and better advertising. Consumer mobility was found to be high in the purchase of natural Christmas trees. In all market areas of the city, consumers traveled an average distance greater than the distance to the next retail lot and, in many cases, twice the distance to the nearest retail lot.

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INTRODUCTION

ANNUALLY, millions of cut natural Christmas trees move to market in the United States. In a 2-month period, these trees flow through a complex market system from thousands of tree plantations and wildlands across the North American continent. Because of the short market period and the geographic dispersion of supply and demand points, market performance is often less than desirable. One basic problem appears to be the inability to determine demand at the retail level.

Losses to the retailer can be substantial if he has little knowledge of his potential sales. If he has too few trees, potential sales may not be realized and, if he carries too many trees, he may depress the market price and have trees left unsold.

THE RESEARCH APPROACH

The intent of this study was to develop information that would provide retailers with more knowledge about sales in a given market area. The study was also designed to relate tree sales for a single Christmas tree retailer to certain variables that are the most important determinants of his sales. Those relationships are expressed as predicting equations, which take the following form:

$$Y = a + bX + cX + \ldots + kX \ ,$$

where Y is the number of trees sold by a given retailer, and X's are variables associated with tree sales, such as price of tree, consumer income, distance from consumer's home to retailer's lot, etc.

Winston-Salem, North Carolina, was chosen as the study area. The city is a Standard Metropolitan Statistical Area (SMSA), for which detailed population and housing information is available by census tract and city block.

A total of 105 economic and demographic variables was analyzed in the study. A survey of Christmas tree retailers was conducted over a 3-year period 1967, to 69, to generate data on 48 economic variables for each retailer and his particular market environment. Also, information on 57 demographic variables was taken from census tract data to characterize the consumers buying trees. In addition, to determine consumer mobility, 1,017 households in Winston-Salem were personally interviewed concerning tree-buying behavior.

An analytical technique, Principal Factor Analysis, was used to identify which of the 105 variables studied were related to a common factor. Once this had been determined, many variables could be dropped, keeping only those that best described a market factor. Regression analysis was used for further screening of the data and for the development of predicting equations.

MARKET RELATIONSHIPS

Retailer Concentration

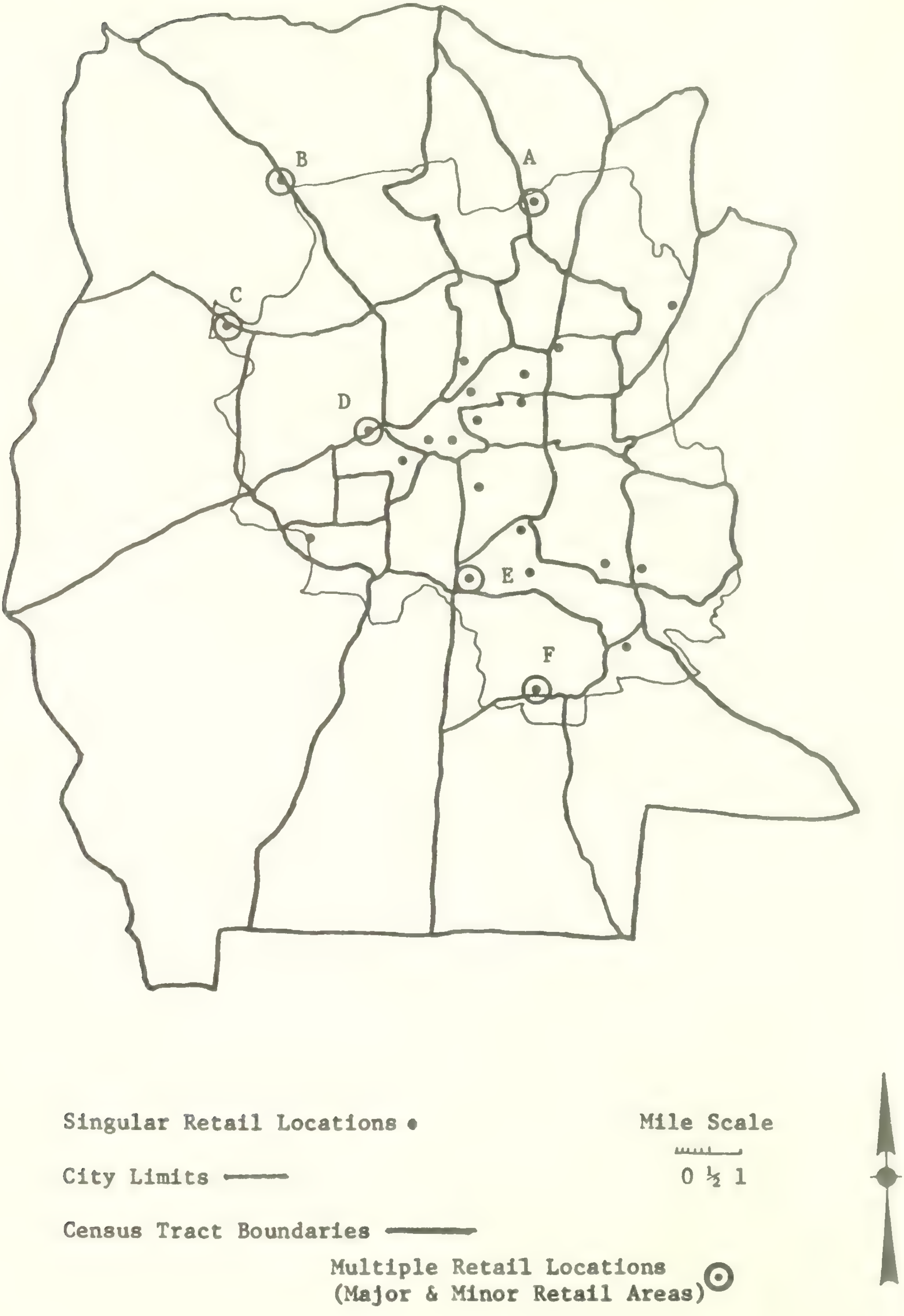
Winston-Salem is like most American cities in its adoption of planned suburban shopping center complexes. The center city still maintains an active retail trade, but significant retail activity has been transferred to the suburbs. Six areas in Winston-Salem were designated as shopping centers or centers of concentrated retail activity (A-F, fig. 1). The principal centers were located at B, D, and E.

Many Christmas tree retailers have, through casual observations or by trial and error, keyed on the transfer of retail activity to the shopping centers. For example, the largest concentrations of Christmas tree retailers in Winston-Salem in 1969 were located at or adjacent to areas D, E, and B in figure 1. The number of retailers located at each was nine, eight, and five, respectively. Further, the two largest retailers in the city were located in area D, the next largest in area E, and the fourth largest in area B. Forty-one percent of the Christmas tree retailers were located in these three retail areas, no larger than 10 city blocks.

Retailers located in or adjacent to shopping centers accounted for 74 percent of the city's total sales of natural Christmas trees. Each tree retailer at these locations held an average of 3 percent of the market, whereas, in the remaining market areas, individual retailers held an average of only 1 percent of the market.

Why are the retailers at these locations? Because these are the most viable Christmas

Figure 1.—Concentrations of Winston-Salem retailers of natural Christmas trees.


A
B
C
D
E
F
Singular Retail Locations ●
City Limits
Census Tract Boundaries
Multiple Retail Locations (Major & Minor Retail Areas)
Mile Scale
0 ½ 1

tree market areas in the city. There are well-defined market associations that show why this is true.

Population, Income, and Distance Traveled

Population has long been cited by economists as a critical factor in the retail sales potential of an area; in fact, it was critical to the Christmas tree retailers' sales in Winston-Salem. This fact does not mean that the retailer should locate in the center of a suburban housing development. However, he should have a location that gains access to an area of potential retail sales.

In figure 1, areas A, B, C, D, E, and F are located on the fringes of the city, defined as suburban by the Census Bureau. Each is approximately 2 miles distant from the others. Areas D, E, B, and A are large multistore shopping complexes, offering services (banking, hair styling, insurance etc.), as well as consumer goods. Areas C and F are central shopping areas with several stores offering mainly consumer goods.

If we define the above areas as separate primary market areas, their potential sales population can be defined as indicated in table 1. We see how critical population can be with the two leading sales areas, D and E. Percentage of market held coincides with population. However, area B provides an excellent example of why demand is not predicated on one or two variables alone, but on a combination of several interacting variables.

Retail area B actually serves more population than is indicated in table 1. Two factors—the type of road system serving this area and the demographic characteristics of the consumer—contribute to making area B a more viable area for tree sales than is indicated by the population count alone. For example, area B is serviced by a major traffic artery, with an average daily traffic count slightly less than that of area E. All the traffic moving northwest from the city passes the area. A second factor contributing to high sales in area B is the predominance of middle- to upper-middle-income families. Higher incomes put more consumer goods, such as Christmas trees, within reach of these households. Also, it gives these consumers more market mobility when they shop.

The greater mobility of middle-income families is indicated by the distance traveled to purchase trees (table 1). Because middle-income families traveled farther, area B, with a 2.5-mile average purchase radius, was obtaining customers from census tracts 4, 25 and 12 (fig. 2). These tracts were not included in the population count because they were assumed to be more closely associated with retail areas C and D.

A counterargument could be presented for area A. It has a very large population in its retail area (23,600) and is serviced by a major traffic artery (15,000 vehicles daily). Yet, area A, with seven retailers, held only 8 percent of the market. The prime limiting factor here is income. Low-income areas were not viable Christmas tree market areas in Winston-Salem. This is true even though these families have many children, a factor that was positive for sales among upper-middle-income families.

The above observation is further supported by

Table 1.—Christmas tree market relationships: Winston-Salem, NC.[1]

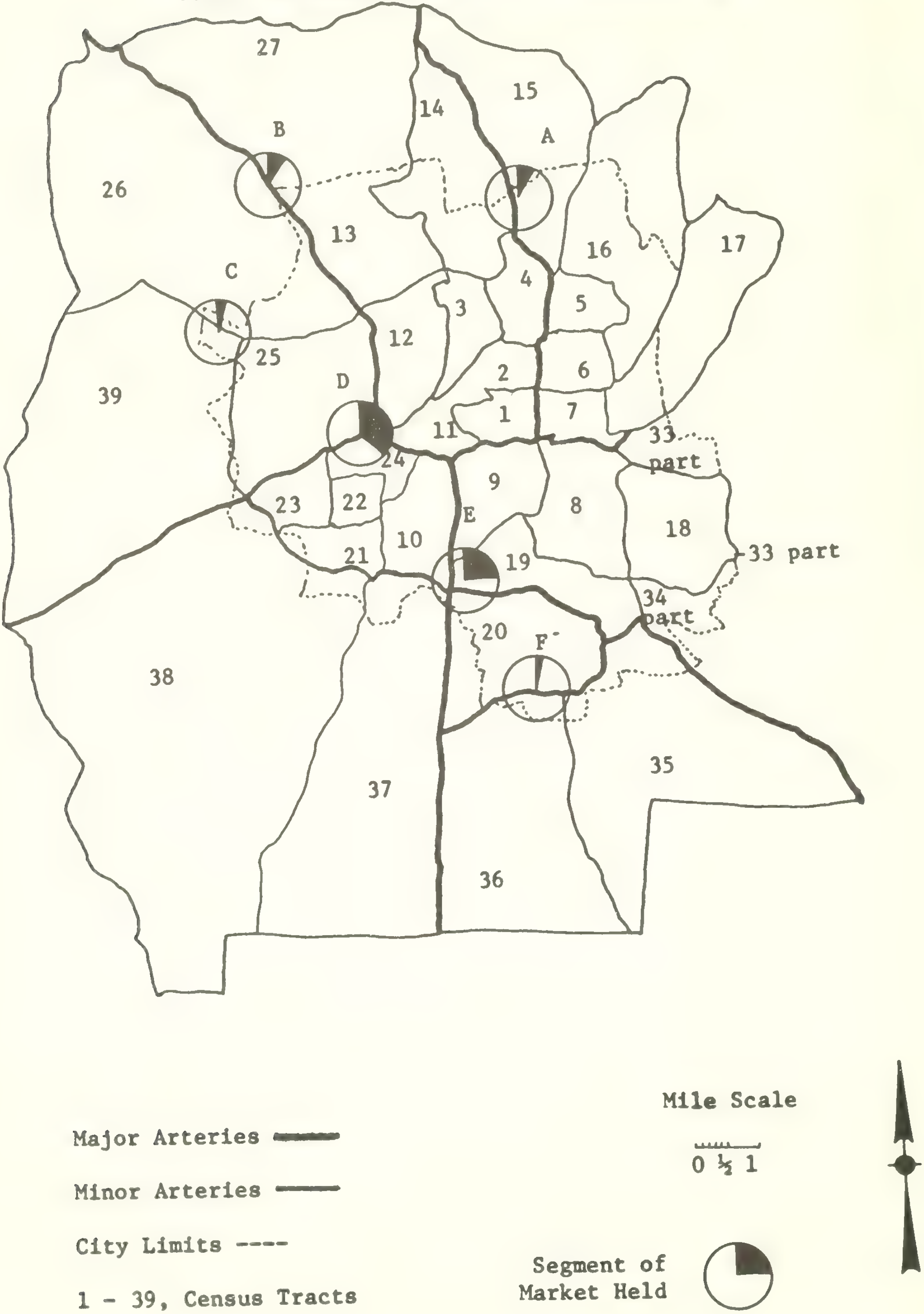
Market area	Distance consumer traveled to purchase tree (miles)	Number of retailers	Population in market area	Average income	Average daily vehicle traffic	Percentage of total market held
A*	2.0	7	23,600	4,700	15,000	8
B*	2.5	5	4,000	8,600	12,000	14
C°	2.0	2	7,300	12,600	7,000	3
D*	2.8	9	31,000	7,600	25,000	37
E*	2.5	8	33,000	6,100	15,000	23
F°	2.5	3	8,000	6,200	7,000	2
G	2.0	17	68,000	4,600	3,000	13

[1] Table based on 1969 retail, consumer, and traffic count data, and 1960 census tract data.

* Major retail area

° Minor retail area

Figure 2.—Winston-Salem major traffic arteries, and the natural tree market held by major and minor retail areas.



retail sales in the diffuse area (G), which also has a high population count. Here 17 retailers, located 6 to 7 blocks apart, each averaged only 0.76 percent of total sales. In area G, two factors were critical; traffic arteries were minor, 3,000 vehicles daily, and income level was the lowest for the city.

We can observe from the preceding analysis that road systems and average income are both associated with the distance that consumers travel to purchase a natural tree. The consumer departs very little from his normal purchasing pattern when buying a Christmas tree. He does not mind traveling to acquire his tree. In fact, he often travels 2 miles to purchase it. Neither does he strive to minimize the effort involved in this purchase. Retailers observed that consumers may shop two or more lots before deciding on a tree and take 10 to 15 minutes to decide on a particular tree.

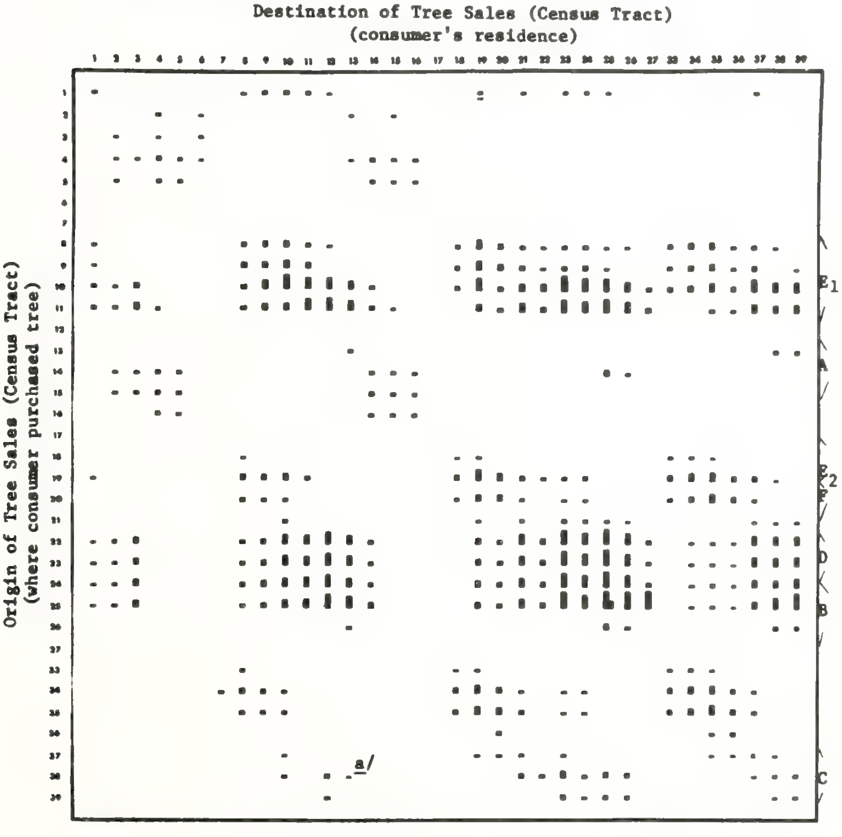
Consumer Mobility

One factor disclosed concerning consumer mobility was a definite relationship between the distance traveled to purchase a Christmas tree and the income of the buyer (table 2). As income increases, people tend to purchase trees farther from their places of residence. For example, householders with incomes less than $3,999 traveled an average of 1.8 miles to buy a tree.

Table 2.—Association between income class and distance traveled to purchase a natural tree.

Income class	Average miles traveled
$< 3,999	1.8
4,000 - 6,999	2.5
7,000 - 9,999	2.8
10,000 +	2.0

Figure 3.—Natural Christmas tree purchase patterns by census tract: Winston-Salem, N.C., 1969.



a/Represents sales of 3 trees.

Householders with incomes between $4,000 and $10,000, traveled between 2.5 and 2.8 miles to buy a tree. Mobility decreased, however, at high incomes, primarily because shopping centers are closer to areas of high purchasing power.

Consumer migration data were developed to assess the origins of sales at a particular location. From these data, a grid showing sales movement was developed to illustrate consumer mobility in selected areas of the city (fig. 3). The figure is constructed to be read from both axes, permitting an evaluation of where tree-buyers lived and to what census tract they traveled to make their purchases.

If all purchases had been made where the consumer lived, the matrix would have all sales recorded on the diagonal, running from the upper left to the lower right. A significant number of tree purchases did occur within the census tract, as depicted by the sales grouped along the diagonal. However, considerable off-diagonal sales appear in the form of horizontal bands. These represent sales at one of the major or minor retail areas.

Persons in low-income census tracts 1-9 purchased their trees from the diffuse retail area and from areas A, D, and E (fig. 1). This is corroborated by the finding that these persons traveled about 1.8 miles to buy a tree, which is only slightly more than the distance across two census tracts in the eastern side of the city. To have gotten out to market areas B, C, or F would have meant traveling 3 miles or farther.

Study of the bands of sales running horizontally across the matrix reveals the origin of tree sales for each market area. For example, area E is composed of pattern E_1 and E^2, located on the corners of census tracts 19, 9, and 10. Those lots sold trees to persons in census tracts 9 to 11 and 19 to 22, all of which bound census tracts 19 and 9 on the north, west, and south. Two major traffic arteries service the area (fig. 2).

Area D, located both in tract 24 and tract 25, was serviced by an interstate expressway and two boulevards, all high-volume traffic roads. The bulk of this area's sales went to census tracts 9 to 12, which are immediately adjacent on the east and northeast; tracts 21 to 26, which are directly adjacent on the south, west, and northwest; and tracts 37 to 39, which surround the general sales area on the south and west.

Further elaboration would only serve to strengthen the argument that consumers do travel considerable distances to select and purchase natural Christmas trees. Also, the percentage that do so is high, approaching 50 percent in most income classes.

At this point in our discussion, we have at least clarified one fact. High retail sales of natural trees are associated with locating the retail lot in or near major retail sales areas. However, acquiring a prime location does not necessarily mean high sales performance. As we have shown, there are many market associations that may contribute to or detract from sales performance. We cannot analyze these associations fully without analytical models.

ANALYSIS OF VARIABLE INTERACTION: FACTOR ANALYSIS

The basic intent of using factor analysis in this study was to condense information contained in our original 105 variables into a smaller number of independent factors (*Harman 1967*). An example will clarify our intent.

Total income provides a good measure of an individual's ability to obtain consumer goods, such as Christmas trees. Yet, purchase of Christmas trees may also be influenced by other related variables, such as family size, value of home, net disposable income, and number of rooms in a housing unit, all of which can be related to total income (*Drysdale and Mansedas 1970, Moore and Box 1970, Thatch and McDonald 1970, Troxell 1969*). Taken together, they provide a more complete picture of a consumer's ability to purchase consumer goods other than necessities. That is, total income reduced by taxes is net disposable income, which when reduced by housing, food, medical care, and other necessities, provides a potential income for purchasing so-called luxury goods and services. Therefore, each variable is partially related to the consumer's ability to buy.

Factor analysis reveals such relationships through correlation analysis rather than mental reasoning. It groups those variables that are associated with a common factor, and analytically determines the amount of variation in that factor that is accounted for by each variable related to it, hence, factor analysis or analysis of factors.

Using the Factors

Our analysis of the 105 variables yielded 19 factors. Each factor can be labeled with a word or term derived from the variables that appear on the factor, e.g., marketing practices. Factors are always given a numbering or ranking sequence, because they are developed by the model in descending order of importance. In our study, Factor II (the primary variables that comprise it) explains more of the variation in all our data collected (105 variables) than does Factor III. Factor IV explains more variation than does Factor V, and so on.

Table 3 lists Factor IV and the top 11 variables that the factor model says are associated; together, they describe a market activity that should be obvious to us.

To interpret the factor, two criteria must be followed:

1. (+) scoring variables are related in a positive manner to the factor, and (−) scoring variables are related in a negative manner;
2. The higher the factor score, the more closely is the variable associated with the factor.

Taking the positive variables first, they describe retailers who were new (no trees last year) or ones who sold fewer trees this year than in the previous year. Also, the retailers didn't advertise, some used discount-store locations and, generally speaking, they had poor-quality lots, i.e., trees on the ground, no signs or lights, etc.

Most retailers would agree that these variables contribute to poor sales performance. In effect, they describe poor market strategies, bad retail practices or low retail performance. Basically, they describe what a retailer shouldn't do if he wishes to be successful.

If the positive scores are associated with poor marketing practices, negative loadings should describe the opposite. In fact, they do just that. They describe retailers in business more than 1 year, advertising in newspapers and with signs, and selling more trees. Thus, Factor IV can be called "marketing practices."

Table 3.—Description of the 11 highest loading variables on Factor IV[1] (Marketing Practices)

Variable score	Description of variable
.89	Relationship of trees purchased this year to last year (no trees)
.89	Relationship of trees sold this year to last year (fewer)
-.70	Advertisement - yes
.70	Advertisement - no
.40	Type of establishment - discount store
-.38	Number of years retailed Christmas trees
-.33	Advertisement - signs
.33	Tree quality - poor
-.31	Advertisement - newspaper
.30	Lot quality - poor
-.28	Relationship of trees sold this year to last year (more)

[1] Factor analysis of 105-variable matrix. Analysis type R-mode, using principal factor solution; number of observations = 53; eigenvalue cut off at 1.00.

Number of Factors

Nineteen principal factors were developed from the 105 variables. The total variance explained for each variable ranged from 0.90 to 0.95. For 105 variables, the total explained variance was 97.81, giving an average of 93 percent explained for each variable. Each of these factors is assumed to be independent (0 correlation) and each, in turn, provides a description of a different source of variance.

Screening the Factors

Our primary reason for creating the factors was to select a smaller number of variables for further analysis. To do this, we selected two or three of the highest-ranking variables on each factor. The screening process resulted in the selection of 43 of the original 105 variables for subsequent regression analysis.

Our effort to describe the Winston-Salem Christmas tree market was intended, in part, to illustrate the complexity of interaction that exists, but is not always apparent. Also, we wished to illustrate that these market relationships can be meaningfully analyzed with models, as in factor analysis. The next, and final, step is to determine if we can predict what will happen in a Christmas tree market based on what we have learned. To accomplish this, we did the following:

- Data on the screened 43 variables were tabulated for all Winston-Salem retailers from 1967-69.
- By use of regression models, predicting equations were developed from these data for each of the 3 study years.

- Using the 1967-69 models, we estimated each retailer's sales for each year, i.e., the 1967 model (Model I) was used to predict sales for every retailer listed in 1967, 1968, and 1969. The same was accomplished for the 1968 and 1969 models.
- Finally, each of the three models was used to estimate tree sales for all retailers in a different market year (1965) and for a different market area (Denver, Colorado).

The Three Predicting Models

The statistics of regression analysis permit us to decide which equations best describe the data from which they are taken. Variables included in the models resulting from our first two steps are presented in table 4. In table 5 are statistical measures of the three predicting models.

Of the three models, Model I is most efficient in describing the data base from which it was

Table 4.—Variables used in predicting equations for sales of natural Christmas trees in Winston-Salem, North Carolina, 1967-69.

1967
MODEL I

$$Y_{ijk} = \mu + \alpha_i + T_j + r_k + \alpha T_{ij} + \alpha r_{ik} + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots$$

(tree sales)

Where

Y_{ijk} = tree sales on i^{th} lot type at the j^{th} location with k merchandising
μ = general mean
α_i = effect of lot location
T_j = effect of lot type
r_k = effect of merchandising
$T\alpha_{ji}$ = lot type x lot location interaction
Tr_{jk} = lot type x merchandising interaction
X_1 = competition among retail lots
X_2 = consumer traffic
X_3 = tree price
X_4 = occupation - laborers
X_5 = persons per household
X_6 = college enrollees

1968
MODEL II

Lot type
Lot location
Interaction of lot type and lot location
Interaction of merchandising and lot location
Competition among retail lots
Population in group quarters
Median family income
Number of households
College enrollees
Median school years completed
Value of housing units

1969
MODEL III

Lot type
Lot location
Interaction of lot type and lot location
Interaction of merchandising and lot type
Competition among retail lots
Tree prices
Population in group quarters
College enrollees

Table 5.—Statistical comparison of predicting Models I, II, and III.

Model	Number of observations (retailers)	Number of variables in equation	Percentage of variation in tree sales explained (R^2)	Standard error
I	53	20	89	111.9
II	46	18	88	175.3
III	53	15	71	239.4

created. It explains 89 percent of the variation in retail lot tree sales in 1967, with the lowest error of estimate for all three models, 111.9. Although Model II explains a similar percentage of total variance in 1968 retail tree sales, it does so with a much higher standard error, 175.3. Model III was much less effective in characterizing variation in 1969 retail tree sales; only 71 percent of sales variation was explained, with a high standard error, 239.4.

A review of the variables in the three models reveals those marketing factors that are important to the Christmas tree retailer. Retail outlet and lot location have been identified as important. Merchandising, competition among lots, and consumer traffic determine exposure to potential sales. Product price and quality, properly paired with the consumer's ability and willingness to pay, set the stage not only for good sales, but for repeat sales from satisfied customers. Good indicators of a consumer's ability and willingness to pay are education, value of the home, occupation, and income. All three models included these variables in making estimates of a retailer's sales potential.

How the Models Work

A non-fictitious retailer in Winston-Salem, to whom we will give the fictitious name Mr. Fir, actually sold 20 trees in 1967. He was located in a small business area in a low-income section of the city. Two other lots were within 4 blocks of his retail lot. Of all retailers studied, his lot had the lowest traffic recorded, 1000 cars. His trees were priced at \$2, and were of low quality. He did not merchandise or advertise his trees. It is apparent that his sales should be low, and the predicting equation painted an even dimmer picture for this lot. Using Model I, Mr. Fir's expected tree sales, as indicated below, would be minus (−) 73 trees:

$$\text{Tree sales } (Y) = -765.41479 + (-188.99060)(X_6) + (120.62463)(X_7) + (-269.23779)(X_8) + (-151.87868)(X_9) + (67.08125)(X_{17}) + (21.89651)(X_{18}) + (9.91129)(X_{19}) + (106.99033)(X_{20}) + (81.26111)(X_{25}) + (9.07497)(X_{27}) + (-40.59557)(X_{30});$$

entering the various variable values,

$$Y = -765.41479 + (-188.99060)(1) + (120.62463)(-1) + (-269.23779)(-1) + (-151.87868)(-1) + 67.08125(2) + (21.89651)(6) + (9.91129)(1.000) + (106.99033)(2.00) + (81.26111)(.69) + (9.07497)(26) + (-40.59557)(4.96) = -73.$$

A second retailer, Mr. Spruce, took an entirely different approach. Mr. Spruce located at a shopping center with the highest traffic count in the city. Although he was close to two competing lots, he advertised and merchandised his trees and lot location and kept good quality trees. As a consequence, he sold 525 trees at the highest average tree price in the city, \$5.48. Predicting his sales with Model I gives the following:

$$(Y) = -765.41479 + (120.62463)(1) + (-151.87868)(1) + (-76.27829)(1) + (187.25530)(1) + (67.08125)(2) + (9.91129)(13.1) + (106.99033)(5.48) + (81.26111)(.04) + (9.07497)(35) + (-40.59557)(.03)$$

$$Y = 545.$$

In the above examples, the 1967 model predicted sales that differed from actual sales. Although it is not precise in its estimates, it accurately characterizes, through its predictability, the effects of "good" and "poor" marketing strategies. Predicting 1968 and 1969 retail lot sales with the 1968 and 1969 (II and III) models was less effective than the 1967 example. However, both were effective in demonstrating the effects of marketing strategies.

The above examples serve only to reveal how well the models predict relationships from data that were, in fact, used to create them. To determine their effectiveness as a marketing tool, they must be tested on a different set of market data. We cannot assume that Model I is the best predictor in a different market environment just because it is an effective predictor for 1967 Winston-Salem market data. It will be effective only if model parameters in the new market are nearly identical to the 1967 Winston-Salem market parameters.

A Test of Model Effectiveness

A 1965 survey of 152 natural tree retailers in Denver, Colorado yielded sales data on that area's natural Christmas tree market (*Troxell 1969*). These data were used to develop variables similar to those we used in the Winston-Salem models and a predicting equation for Denver. Also, the data were used to test the predicting efficiency of the three Winston-Salem models.

The two metropolitan areas differed significantly, both in population demographics and in natural Christmas tree retail sales activity. Denver had four times the number of households and a greater average household income. Eleven times as many trees were sold in Denver as in Winston-Salem. A total of 92 percent of households purchased trees, more than 60 percent of which were plantation grown.

Our comparisons of all four models in all four markets gave the expected results. Their accuracy had been expected to decrease over time in the same market, and such a decrease is suggested. The models had been expected to perform more poorly in a new market, and such a result seems obvious from tests of the Winston-Salem models on Denver data.

Table 6 was developed from a statistical analysis of the difference between actual retailer sales in a market and the sales predicted by the model. The analysis of these differences, defined as average squared residuals, provides a measure of accuracy for each model on each set of market data.

Table 6.—Average squared residuals of predicted Christmas tree sales in four markets

Model	Data sets			
	Winston-Salem			Denver
	1967	1968	1969	1965
I	**7,567**	65,717	95,028	837,306
II	121,903	**18,043**	90,750	776,512
III	47,035	60,346	**40,004**	798,621
Denver	1,424,811	1,085,028	2,140,043	**364,399**

The model developed from a specific data set was always the most accurate predictor of actual market sales represented by that data set. This is indicated by the fact that the diagonal values in table 6 are the lowest for each column. Each data set is different, and so is each model. For Model I to have equal predicting accuracy on 1967 and 1968 data sets would require the data and, therefore, the models to be identical. Sales data did differ over the 3 years in Winston-Salem. Further, the Winston-Salem and Denver data have extreme differences.

A second supposition, using the above argument, would be that the Denver model should have lower accuracy on Winston-Salem data sets than on the Denver data. This fact is demonstrated in table 7, in which the performance of each model is ranked for each data set. The Denver model was ineffective in predicting Winston-Salem tree sales. By contrast, the Winston-Salem Models were much more effective in the Denver market. Also, all three models produced similar squared residuals (table 6).

Table 7.—Relative accuracy of four predicting equations on four sets of Christmas tree retail sales data

Model	Data sets			
	Winston-Salem			Denver
	1967	1968	1969	1965
I	**I**	III	III	IV
II	III	**I**	II	II
III	II	II	**I**	III
Denver	IV	IV	IV	**I**

Table 8.—Model error in predicting actual tree sales for the average retailer in four markets (trees per lot)

Model	Data sets			
	Winston-Salem			Denver
	1967	1968	1969	1965
I	87	256	308	915
II	349	134	301	881
III	217	246	200	894
Denver	1193	1041	1463	604

Although the models are effective in describing the characteristics of markets for natural Christmas trees, their utility for direct application in market management is restricted. The models do not effectively predict sales at the retail level. Table 8 presents the average error each model incurred in predicting the average retailer's tree sales in a given market. Model I errs in its estimate of the average retailer's sales by 87 trees per lot. Model II errs by 349 trees, and the Denver Model errs by twice the actual sales. A similar pattern exists in all markets.

Analyzing Residual Plots

Although much can be gained from the statistical tests of the models in table 6, certain inferences are lacking. To obtain a more in-depth look at the performance of the models, it is necessary to look at the residual plots, more specifically $(Yi-\hat{Y}i)^2/\hat{Y}i$.

The plots support the statistical analysis of the residuals. The pattern of residuals for Model III fully characterizes a large variance, which is not constant (fig. 7). In fact, the assumption of constant variance appears to be violated at both high and low values of Y. Further, it is more severe in Model III than in any other model.

A fact not indicated by the foregoing analysis of residuals is that estimates of Denver sales yield a somewhat constant variance over lot size. In fact, residual variance created from each model's estimates of Denver retail sales has the greatest uniformity of all residuals analyzed (figs. 4 and 5). Conversely, residuals created from use of the Denver Model to predict sales on 1967-69 Winston-Salem retail data reveal greater variances for larger retail lots (fig. 6).

Model I had the least variation in the residuals, although there is evidence of a need for weighted least squares or variable transformation (fig. 4). Yet, the probabilities of improvement are minimal when Model I is compared with the Denver Model.

The Denver Model reveals the greatest potential for improvement. It is the most effective estimator on lot sizes up to 1,000 trees; at that point, the variance increases radically. Model II has plots similar to Model III, revealing a change in residual variance from small to large lots (figs. 5 and 7).

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be drawn from this research. Based on these conclusions, recommendations can be made that will not only provide greater meaning to these investigations, but should also be valuable to future research.

Conclusions

Competition did exist in the Winston-Salem retail market for natural Christmas trees. Although there was obvious concentration of seller activity, there were no controls imposed on market activity by this concentration. Perfect competition, however, could hardly be expected with the limited information system available to retailers.

Consumer mobility in the purchase of cut natural Christmas trees was high. Low-income buyers residing in areas where single lots were less than 1 mile apart traveled an average of 1.8 miles to purchase their trees. Median-income families traveled the greatest distance (2.8 miles), while residing in areas where concentrations of retailers averaged 1.2 miles from the consumer. In all sectors of the market, consumers traveled an average distance that exceeded the average distance to the nearest retail lot.

The greatest retail sales activity occurred in areas of concentrated retail sales for other products. About half of the cut natural tree retailers were located there, and they held approximately 70 percent of total market sales. Other products and services offered at these centers are important to the sales of natural trees. They afford convenience to the consumer, with large parking areas, sufficient area for product display, and access to other stores for

Figure 4.—Squared residual plots of estimated Denver retail sales with Model I.

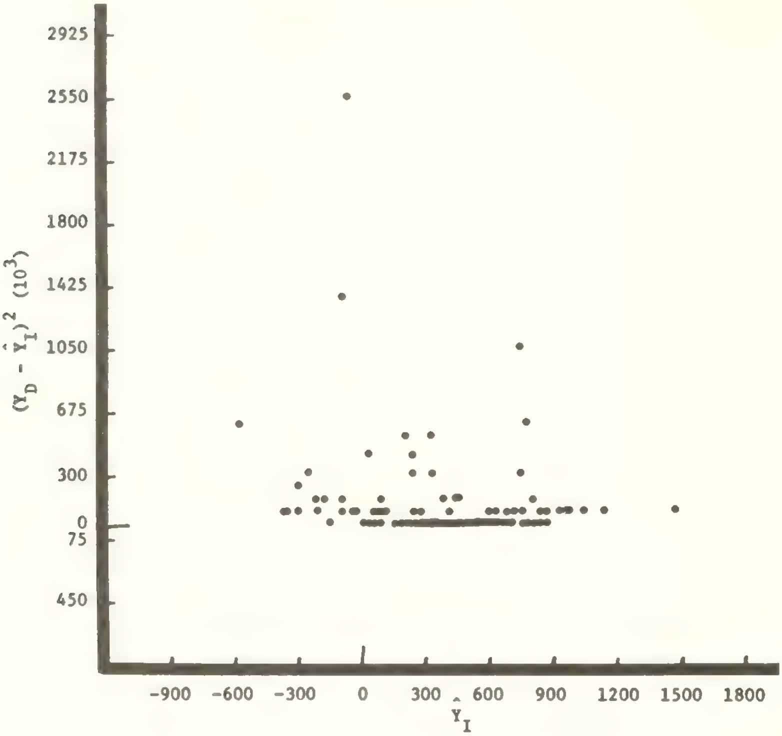


Figure 5.—Squared residual plots of estimated Denver sales with Model II.

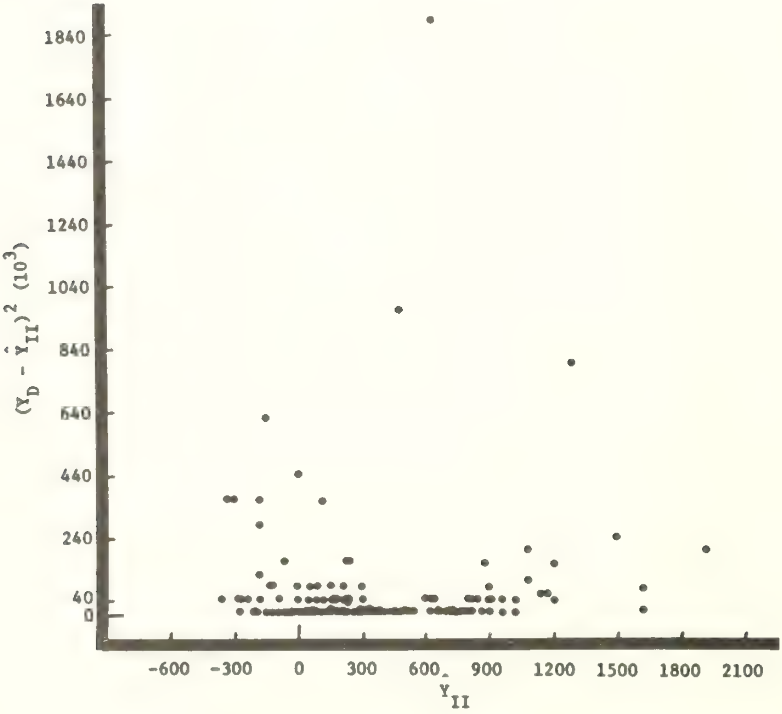


Figure 6.—Squared residual plots of estimated 1967 Winston-Salem retail sales with the Denver Model.

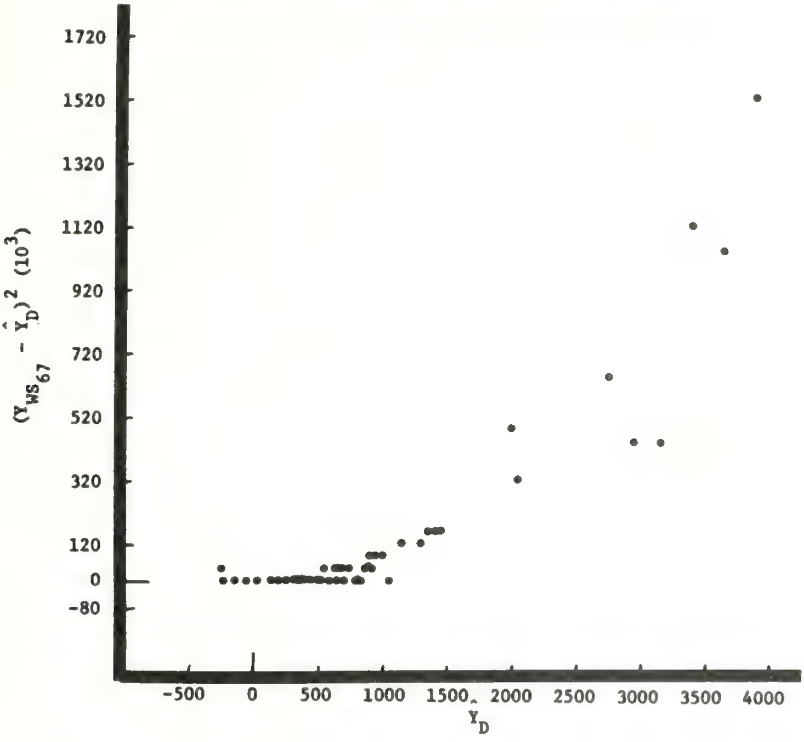
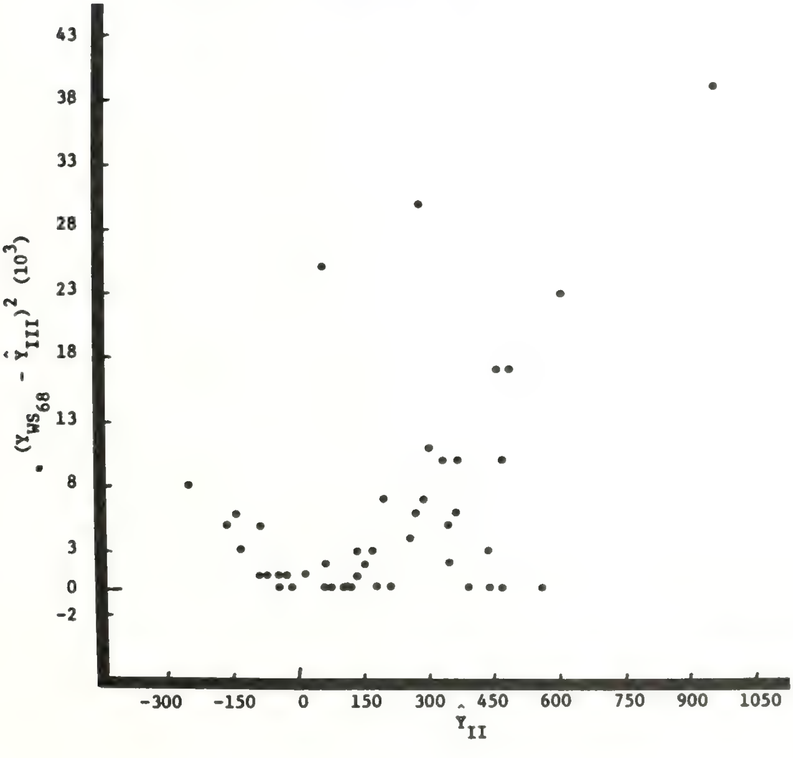


Figure 7.—Squared residual plots of estimated 1968 Winston-Salem retail sales with Model III.



normal shopping activity. Also, such market activities as advertising and merchandising are greatly facilitated at these locations. Therefore these centers represent prime locations for retailing Christmas trees in metropolitan areas.

Factor analysis was effective in delineating independent spheres of influence from variables used in the analysis. However, factor and regression analysis, like other analytical tools, depend on good empirical data. Creation of the predicting equations was hampered by limitations on availability of current and reliable census data and our inability to quantify certain variables correctly. Yet the models did effectively characterize the market relationships observed.

The use of predicting equations as developed herein has restricted application to direct market management. The models are structured around marketing factors that are exceedingly dynamic; they are ever-changing, and often occur in differing proportions. Further, variance was not concentrated in one variable but in many, making it difficult to monitor the changes.

The equations developed demonstrate statistical significance and are effective in identifying market associations. Yet, their accuracy at the retail level is insufficient for them to stand alone as a management tool. They are effective in characterizing market strategies being used at the retail lot level. Further, the models do differentiate the market effect of "good" versus "poor" market strategies.

Recommendations

This research has demonstrated that a myriad of marketing and economic factors affect the sales performance of a given retail lot. Although some factors are more important than others, several must be included to have an acceptable estimator. From one lot to another, within the same market, these factors will change in level of importance to the dependent variable (sales). More importantly, changes in market conditions with time, geography, or both will likely cause even greater variability.

This sensitivity at the retail lot level limits the effectiveness of the models. The potential for predicting error is too great to permit dependence solely on the model for decision-making. Instead, the model could and should be used for market analysis. If the retailer studies a cross-section of potential lot locations, he can rank the areas by estimated sales performance. Patterns similar to those in Denver and Winston-Salem should become apparent. These evaluations could then be used for selecting the best lot locations.

Future research should concentrate on defining interrelationships among the variables studied. This research was directed at obtaining effective estimators, with limited attention being paid to assessment of individual variables. Extensive descriptive studies have been made, focusing attention on many factors that are important to retail sales. More definitive work is necessary to determine the exact impact these variables have on sales and on each other.

Once analytical relationships have been established for important variables, attempts should be made to develop regional models. Systematic aggregation of retail outlets to larger, more homogeneous groups, either a priori or via empirical evidence would be a natural extension of the work presented here. It should incorporate time as a variable, to allow for the effects of changes in and competition from other products.

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Morphological and Physiological Factors Affecting Formation of Adventitious Roots on Sugar Maple Stem Cuttings

by John R. Donnelly

USDA FOREST SERVICE RESEARCH PAPER NE-365
1977

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JOHN R. DONNELLY was employed as a Research Forester at the Northeastern Forest Experiment Station's laboratory at Burlington, Vermont, at the time this study was made. He is now Associate Professor of Forestry at the University of Vermont, Burlington.

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Morphological and Physiological Factors Affecting Formation of Adventitious Roots on Sugar Maple Stem Cuttings

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ABSTRACT

Sugar maple cuttings were collected twice a week throughout June from four mature trees. Some of the cuttings were analyzed for carbohydrate (starch and sugars) and nitrogen content; the others were stuck in rooting beds. Rooting response showed significant daily and clonal variations. Cuttings rooted best when their terminal leaves were mature, as judged by size and color. Daily changes in rooting response were only weakly correlated with sugar and nitrogen concentrations, but rooting response peaked soon after a marked rise in starch.

Keywords: Rooting, vegetative propagation

INTRODUCTION

SUGAR MAPLE (*Acer saccharum* Marsh.) is considered to be a difficult species to propagate vegetatively. Some cuttings root well, while many root poorly or not at all (*Donnelly 1974; Gabriel et al. 1961*). Response also varies with the time of year at which cuttings are collected (*Dunn and Townsend 1954; Enright 1958; Koelling 1968; Snow 1941*). Koelling collected cuttings at 2-week intervals from nine trees in Vermont during the period 3 February through 19 July, and found that no dormant cuttings rooted. Rooting improved as current-year shoots developed, was at its maximum in early June, and decreased through July. Apparently, sugar maple cuttings root best when collected in late spring, but the 2-week interval between collection periods in Koelling's study made it impossible to pinpoint the optimum time for collection.

In an attempt to refine the criteria for optimal selection of sugar maple cuttings, the rooting response of cuttings that had been collected twice a week throughout the month of June was monitored and compared with changes in physical appearance of the cuttings. Changes in carbohydrate and nitrogen content of the cuttings were also compared with rooting response.

METHODS

Twice a week during the period 2 June to 30 June 1967, 30 cuttings were collected from each of four mature sugar maple trees near Burlington, Vermont. Each cutting was an entire current-year shoot. Twenty of the cuttings from each tree were placed in rooting beds in a greenhouse. The 10 remaining cuttings from each tree were analyzed for starch, ethanol-soluble sugar, and nitrogen.

The cuttings to be rooted were placed in a 1:1 mixture of coarse Perlite[1] and shredded sphagnum moss. Minimum and maximum air temperatures in the 6 x 18-m plastic-covered greenhouse were about 16 and 32°C. Heating cables maintained the rooting medium at 27°C. Each cutting was wounded and dipped into undiluted Hormodin No. 3 before being inserted to a depth of 5 cm into the rooting medium. Cuttings were fertilized with a complete nutrient solution incorporated into the electronically controlled mist system (52.7 g of Rapid-Gro dissolved in 1000 ml of water; 7.5 ml of this solution was incorporated into each 1000 ml of water added through the mist system). Supplemental lighting (150-watt incandescent lamps placed about 1 m above the rooting beds) provided a 20-hour daylength. All cuttings were examined for root formation in mid-September, about 3-1/2 months after the first of them had been stuck in the rooting beds.

The cuttings for analysis were cut into small pieces that were mixed together; three 2-g samples were extracted with hot ethanol and analyzed for carbohydrates by procedures modified from Morris (*1948*), Hodge and Hofreiter *(1962)*, Horwitz *(1960)*, Ward and Johnston (*1962*) and Witherell (*1963*). Three additional 1-g samples were analyzed for total nitrogen by the University of Vermont, College of Agriculture, Regulatory Service.

RESULTS AND DISCUSSION

Morphological appearance.—The trees included in this study broke bud around the middle of May. On 22 May, individual leaves were distinguishable, and some shoots had grown to 5 cm. Shoots on two trees were further developed than those on the other two trees at this time, but, at later observation periods, all trees appeared to be at the same stage of development. By 2 June (the date of first collection), shoot stems were about 13 cm long and quite succulent, leaves were reddish-green, and the new terminal bud had not formed. By 6 June, stems were fully elongated and noticeably firmer. By 9 June, new terminal buds were visible. By 13 June, the terminal bud was enclosed within two dark-brown scales and, by 20 June, leaves appeared to be mature, as judged by size and color. No further changes in appearance were noted during later collections except that the stems of a few cuttings began to turn brown in late June.

Rooting response.—The average rooting response for all four trees increased from 16 per-

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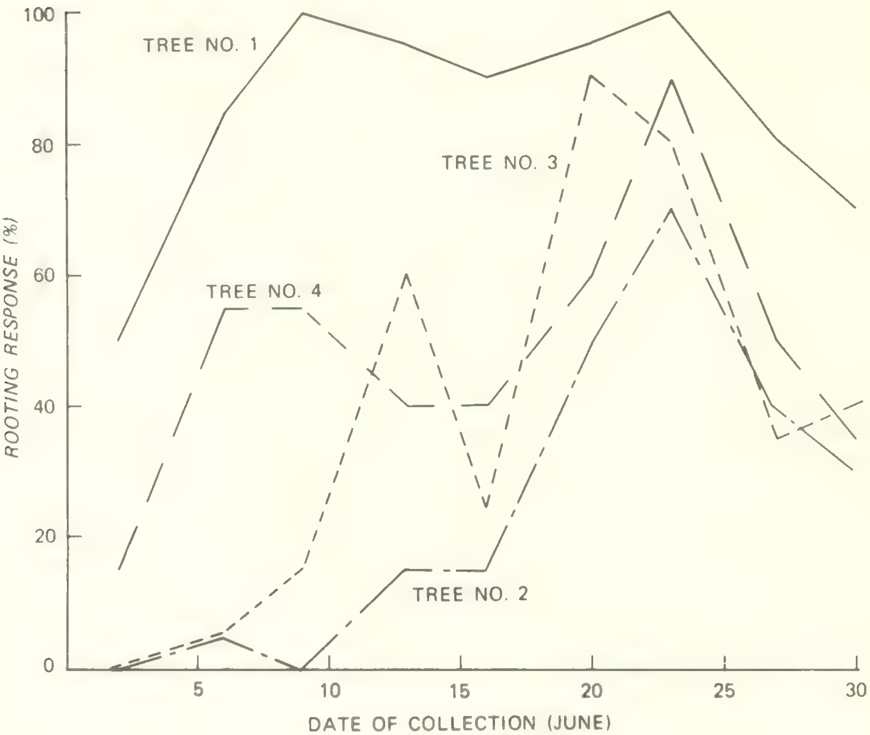
[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 1.—Rooting response of sugar maple cuttings taken during June from four trees.



cent on 2 June to 85 percent on 23 June, then decreased to 44 percent by 30 June. There were clonal as well as daily variations in rooting response (Fig. 1). Tree No. 1 had consistently higher rooting responses than the other trees. Rooting trends in the last 2 weeks were similar for trees No. 2, 3, and 4. All trees rooted well during the third week of June.

Gabriel et al. (*1961*) studied clonal variations in the rooting response of cuttings from 46 mature sugar maple trees. Rooting response varied from 1.4 to 46.1 percent, but it is impossible to attribute this response solely to inherent clonal variation, because cuttings were collected in late June and early July, rather than all at the same time. As indicated in figure 1, rooting potential may drop off drastically during this period. Donnelly (*1974*) collected cuttings from three mature sugar maple trees in a study designed primarily to test the effect of shoot size on rooting. Even though all cuttings were collected at about the same time (mid-June), the average rooting response varied from 1 to 61 percent.

Chemical analyses.—It was difficult to detect any trend in the sugar concentration of the cuttings because of large tree-to-tree and day-to-day variations but, in general, the sugar concentration decreased slightly during the first half of June, then remained relatively constant through the remainder of the test period (fig. 2). The concentration of nitrogen decreased consistently in early June and then leveled off. The concentration of starch changed little during the first half of the month, rose sharply between 16 June and 20 June, then decreased slightly. The sharp rise in starch concentration in mid-June coincided with the apparent maturation of developing shoots.

Factors correlated with rooting.—These cuttings collected between 20 June and 23 June rooted best. But Koelling (*1968*) found that cuttings from maple trees in the same general area rooted best when collected in early, rather than late, June. This difference is probably due to a difference in the timing of shoot development, and undoubtedly reflects variations in spring weather conditions. Perhaps the most important month to consider is May, when a new flush of growth can be expected. May 1965, when Koelling conducted his experiment, was warmer (approximately 6°C), drier (5.4 cm less rainfall), and sunnier than May 1967.[2] These disparities were presumably responsible for a difference between Koelling's work and ours in the rate of shoot maturation and, consequently, in the collection date of those cuttings that rooted best. Because of yearly variations in local weather conditions, date of collection is not a good criterion for pinpointing the optimal time when cuttings should be collected. Relative length of shoots was not a useful criterion either, because shoot elongation was no longer occurring in the cuttings that rooted well.

The morphological characteristic most noticeably associated with rooting potential was the color of terminal leaves. Cuttings rooted best when the tip (last formed) leaves were already mature, as judged by size and color. At that time, the shoot's stem was still green, and a new terminal bud had formed. The terminal bud was about 0.25 cm long and appeared to consist of two dark brown scales. This description of the optimum stage of development agrees with that given by Koelling (*1968*).

A high percentage of cuttings from all trees rooted when they were at this stage of develop-

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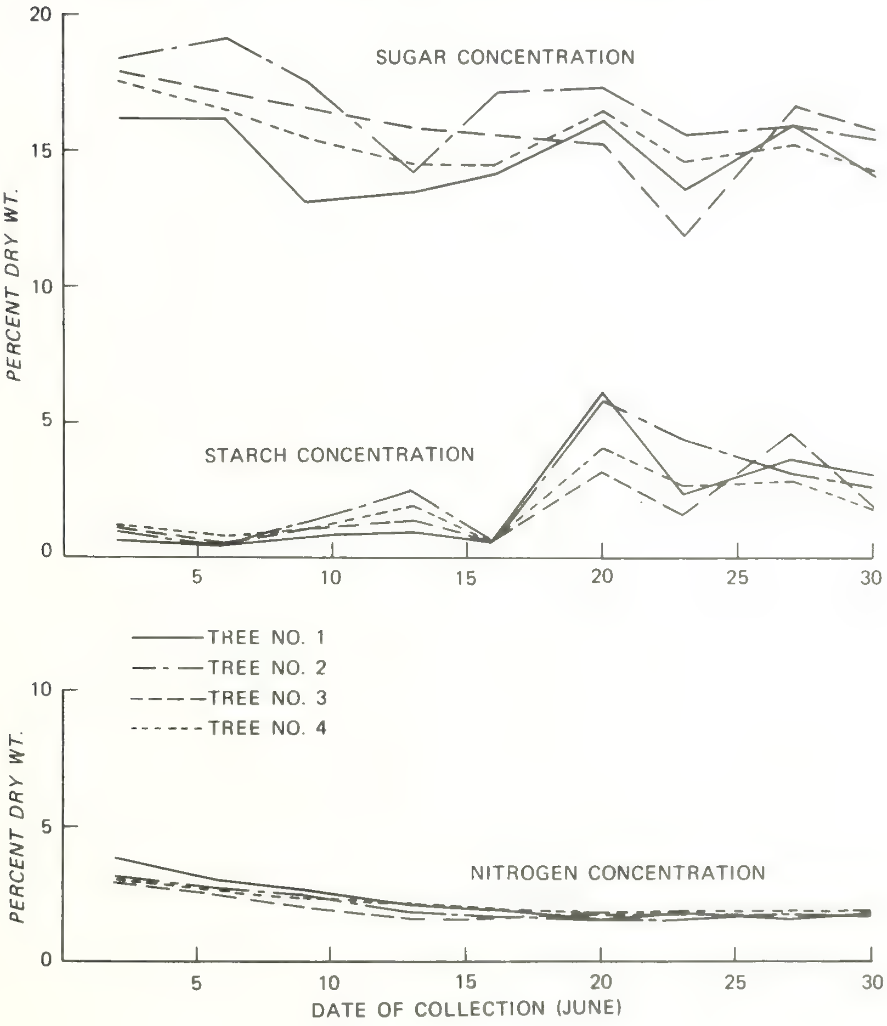
[2] Source: U. S. Weather Bureau, Burlington, Vermont.

Figure 2.—Sugar, starch, and nitrogen concentrations in cuttings taken from four sugar maple trees during June.



ment. But cuttings from tree No. 1 rooted equally well when they were quite immature. In fact, immature cuttings from this tree rooted better than did cuttings from most other trees that were at the presumed optimum stage of development (fig. 1). Consequently, the value of morphological appearance as a criterion for selection seems limited. Appearance provides a general guideline for determining at what time cuttings should be selected, but it does not indicate how well these cuttings will root, nor does it explain why cuttings from certain trees root better than cuttings from others.

For several plant species, rooting of cuttings is promoted by high endogenous levels of carbohydrate and inhibited by high levels of nitrogen (reviewed by *Hartmann and Kester 1968*). To test whether such a relationship exists in sugar maples, daily changes in the rooting response of cuttings from individual trees were correlated with daily changes in carbohydrate and nitrogen levels in the cuttings (table 1). For each tree, the rooting response was negatively correlated with sugar and nitrogen concentrations and positively correlated with starch concentration and the carbohydrate:nitrogen ratio. Correlation coefficients were generally quite low. Linear regression showed that only 4 of the 20 correlations tested were significant at the 0.05 level. Three of the statistically significant correlations were for tree No. 2 and the other was for tree No. 3. The average correlation coefficient was 0.75 for tree No. 2 (the poorest rooter), but only 0.37 for tree No. 1 (the best rooter). These results are similar to the correlations between rooting response and morphological stage of development, i.e., the rooting response of cuttings from tree No. 2 was closely correlated with stage of development and relatively well correlated with carbohydrate and nitrogen content; in contrast, cuttings from tree No. 1 rooted well at various stages of development, and rooting response was not well correlated with carbohydrate or nitrogen level. The average correlation coefficients for trees No. 3 and 4 were 0.57 and 0.40 ,respectively. These trees were intermediate in terms of rooting response and degree of correlation between rooting and carbohydrate and nitrogen content.

Average correlation coefficients for all four trees ranged from 0.47 for starch to 0.61 for nitrogen (table 1). Although starch concentration was generally not well correlated with rooting response, the date of maximum response (23 June) coincided, approximately, with a marked increase in concentration of starch. Most current-year photosynthates are respired or assimilated into plant biomass while shoots are rapidly developing, but starch accumulates when developing leaves have matured and shoot elongation has ceased. At about that same time, shoots are at their maximum rooting potential. Although there may be no direct cause and effect relationship between rooting response and a sharp rise in concentration of starch, the two seem to be related. Molnar and LaCroix (*1972*) found that hydrangea cuttings with a high starch content rooted better than did those with a low starch content. In contrast, Nanda and Anand (*1970*) reported a negative correlation between rooting and starch content in *Populus nigra*. The authors equated rooting potential with the

Table 1.—Correlation coefficients between percent rooting and average concentrations of carbohydrates and nitrogen in cuttings taken semi-weekly during June.

Tree number	Independent variable			
	Percent sugar	Percent starch	Percent nitrogen	C/N ratio
1	-.53	.14	-.56	.24
2	-.46	.87**	-.77*	.89**
3	-.81**	.46	-.65	.37
4	-.26	.42	-.47	.46

*Significant at 0.05 level.
**Significant at 0.01 level.

presence of enzymes capable of mobilizing the food reserves. I did not analyze for enzymes in this study.

CONCLUSIONS

Softwood sugar maple cuttings rooted best when collected immediately after their leaves had matured. Rooting was not well correlated with concentrations of sugar or nitrogen, but peak rooting activity coincided approximately with a sharp rise in concentration of starch. If this apparent coincidence is meaningful, a rapid field method for determining starch content may be useful in deciding when to collect cuttings from high-yielding maple trees.

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5 p., illus. (USDA Forest Serv. Res. Pap. NE-365)

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232.328.1 176.1 *Acer saccharum* Marsh.

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MANUSCRIPT RECEIVED FOR PUBLICATION 8 OCTOBER 1976

ABSTRACT

A large portion of logging residues and materials removed in thinning consists of trees 1 to 10 inches dbh (diameter at breast height). As part of research to achieve increased utilization of these small trees, whole-tree weight tables and prediction equations were developed for small Appalachian hardwoods, based on a sample of 200 trees of 17 species from a site in central West Virginia. Average green weight of the trees (all material above a 6-inch stump) was 434 pounds, 80 percent of which was in material greater than 3 inches d.o.b. (diameter outside bark). The weighted average moisture content of the 200 trees was 69 percent, oven-dry basis. Whole-tree weight tables (green and oven-dry basis) were developed from the formulas: $\mathrm{Ln(GWT)} = 1.54934 + 2.39376\ \mathrm{Ln\ (DBH)}$ and $\mathrm{Ln\ (ODWT)} = 0.95595 + 2.42640\ \mathrm{Ln\ (DBH)}$; where GWT = whole-tree green weight in pounds, ODWT = whole-tree oven-dry weight in pounds, DBH = diameter breast high, and Ln = natural logarithm function.

THE CONCERN

BECAUSE OF ANTICIPATED INCREASES in demand for forest products and public concern about the apparent waste of wood during timber harvesting, both forest managers and timber processors have become more interested in the utilization of logging residues. In response to this concern, personnel at our Forest Products Marketing Laboratory at Princeton, W. Va., are conducting research to develop commercial uses and markets for logging residues in the Appalachian Region. The initial studies were designed to quantify and characterize residues in terms of their suitability as industrial raw material.

This report provides information about weights, moisture content, and percentage of bark for hardwood trees 1 to 10 inches dbh (diameter at breast height). These small trees are usually unsuitable for use as sawlogs, and they are often felled and left in areas where sawtimber has been harvested by clearcutting. And many of the trees removed in thinnings are in the 1- to 10-inch dbh range.

The data in this report will enable forest managers, forest-products manufacturers, and others engaged in efforts at closer timber utilization to estimate green and oven-dry weights for individual trees or stands of Appalachian hardwoods.

PROCEDURE

During the summer and fall of 1975, 200 whole trees—the entire tree from a 6-inch stump to the top—were weighed, 20 in each 1-inch dbh class from 1 to 10 inches. The trees were selected randomly from the top to the bottom of the slope. The stand, located on the Monongahela National Forest near Richwood, W. Va., had a predominantly oak overstory and a maple understory. Slope averaged about 30 percent; site index for red oak averaged 80.

I recorded tree number, species, and dbh to the nearest 1/10-inch, and total height to the nearest foot. Each tree was then cut into pieces and weighed with a portable 500-pound capacity straight spring scale (fig. 1). A cut was made at each point where the tree bole or limb diameter was 3 inches d.o.b. (diameter outside bark). Tree portions greater than 3 inches in diameter were weighed and recorded separately from portions less than or equal to 3 inches in diameter.

Sample disks were cut from each tree for determining moisture content and percentage of bark. One sample disk was taken from near the mid-stem of trees 1 to 2 inches dbh. Two sample disks were taken from trees 3 inches dbh or larger; one from the stem midway between the stump and the 3 inch d.o.b. cutoff point, and one at random from branch wood less than 3 inches d.o.b. Each disk was labeled with the tree number and disk diameter and put in an airtight plastic bag.

Later the same day, the sample disks were weighed and the weights were recorded. The entire disk was weighed first, then the bark was hand-peeled and the resultant bark-free disk was reweighed. Weight difference was recorded as green bark weight. The peeled bark was kept in a bag with the corresponding sample disk to maintain its identity. The wood disks and bark samples were then oven-dried and reweighed for determining moisture content of wood and bark.

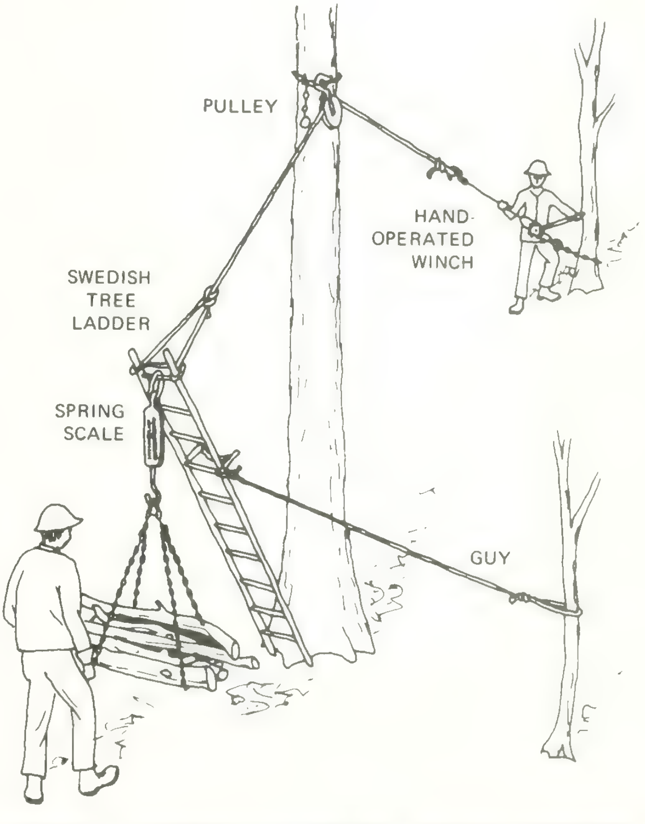

Figure 1.—System for weighing logging residues.

Regression analyses were used to develop equations for tree weight as a function of dbh.

RESULTS

Average green whole-tree weight was 434 pounds. Eighty percent of this weight, 349 pounds per tree, was in portions of the trees greater than 3 inches d.o.b. The remaining 20 percent, 85 pounds per tree, was in the portions less than or equal to 3 inches d.o.b.

Whole-tree weight estimates (table 1) were computed by using equations developed by regression analyses. Natural log transformations on whole-tree weight and dbh gave the best fit. The equations developed were:

$$\mathrm{Ln(GWT)} = 1.54934 + 2.39376\,\mathrm{Ln(DBH)} \quad R^2 = .97$$
$$\mathrm{Ln(ODWT)} = 0.95595 + 2.42640\,\mathrm{Ln(DBH)} \quad R^2 = .97$$

Where

GWT = Whole-tree green weight (in pounds).
ODWT = Whole-tree oven-dry weight (in pounds).
DBH = Diameter at breast height ($1'' \leq \mathrm{dbh} \leq 10''$).
Ln = Natural logarithm function.

For predicting the weights of portions of trees, the ratios of weight of the portions larger than 3 inches to whole tree weight were calculated for each tree and regressed on dbh. The resulting best-fit equation was $PG = 0.83059 - 14.57918 \times \mathrm{Exp}[-\mathrm{DBH}]$, where PG = proportion of weight in material larger than 3 inches d.o.b. This same equation was found acceptable for green and oven-dry weights. Then the percentages were applied to whole-tree weights to get table values for material larger than 3 inches d.o.b. These values were subtracted from whole-tree weights to determine the table values for weights of tree portions less than or equal to 3 inches d.o.b.

Weights shown in table 1 include the 17 different hardwood species shown in table 2. Scatter diagrams showed very little difference in the green weights of different species: soft hardwood trees weighed slightly less than hard hardwoods of the same dbh. The soft hardwoods generally had higher moisture contents, which compensated for differences in specific gravity. Since our sample distribution (table 2) included so few soft hardwoods, no statistical tests were made for differences between species or species groups.

The overall weighted average moisture content of the 200 trees was 69 percent. The moisture contents for the green weights varied by species from 54 to 114 (table 2). These average moisture contents for each species were weighted by the proportion of residue weight represented by each sample disk.

Moisture content and percentage of bark varied with disk diameter (fig. 2). Wood moisture content was 70 ± 5 percent over the 1- to 8-inch disk diameter range. The bark moisture content gradually decreased over the diameter range from a high of 96 percent at 1 inch to a low of 61 percent at 8 inches.

The overall weighted bark percentage on a

Table 1.—*Small Appalachian hardwood tree and component weights* [a]

Tree dbh (inches) [x25.4=millimeters]	Green[b]			Dry			Average height (feet) [x0.3048=meters]
	>3"	≤3"	Whole tree	>3"	≤3"	Whole tree	
	pounds						
1	—	5	5	—	3	3	16
2	—	25	25	—	14	14	24
3	7	58	65	4	33	37	31
4	73	57	130	42	33	75	40
5	163	59	222	94	35	129	46
6	273	70	343	160	41	201	50
7	406	90	496	239	53	292	55
8	564	119	683	334	70	404	59
9	751	155	906	446	92	538	70
10	968	198	1,166	576	118	694	70

[a] Weights represent 17 species. Weighted average percentage of bark (green-weight basis) is 16. To convert weights from pounds to kilograms, multiply by 0.454.

[b] Weighted average moisture content (oven-dry basis) is 69 percent.

Table 2.—*Species distribution and weighted average moisture content and percentage of bark, by species*

Species	Trees	Weighted average [a] moisture content	Weighted average [b] bark percentage
	No.	*Percent*	*Percent*
Soft Maple *(Acer rubrum)*	47	69	16
Chestnut Oak *(Quercus prinus)*	32	64	20
Red Oak *(Quercus spp.)*	31	75	16
White Oak *(Quercus alba)*	28	66	17
Hickory *(Carya spp.)*	13	54	17
Sourwood *(Oxydendrum arboreum)*	12	88	14
Hard Maple *(Acer spp.)*	9	64	14
Sassafras *(Sassafras albidum)*	7	64	14
Black Gum *(Nyssa sylvatica)*	4	89	19
Yellow-Poplar *(Liriodendron tulipifera)*	4	104	19
Mountain Magnolia *(Magnolia fraseri)*	3	97	17
Aspen *(Populus spp.)*	2	78	23
Beech *(Fagus grandifolia)*	2	78	10
Cucumber *(Magnolia acuminata)*	2	107	17
Dogwood *(Cornus Florida)*	2	71	13
Black Cherry *(Prunus serotina)*	1	95	15
Sweet Birch *(Betula lenta)*	1	114	18

[a] Oven-dry basis.

[b] Green-weight basis.

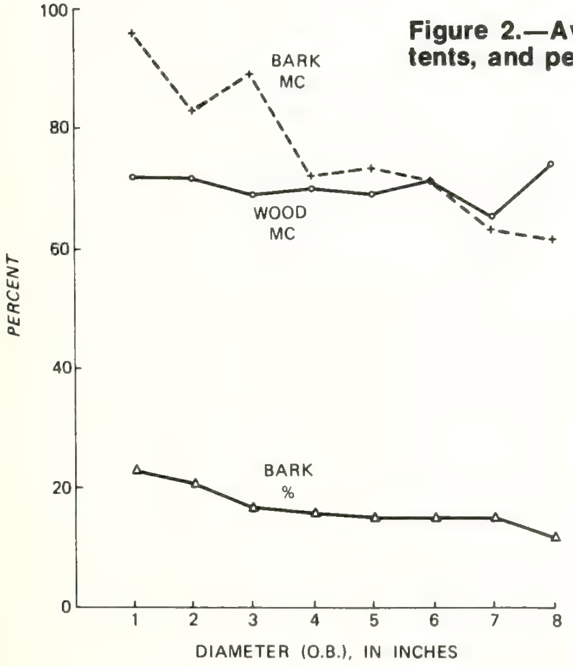

Figure 2.—Average wood and bark moisture contents, and percentage of bark versus diameter.

green-weight basis was 16. The bark percentage decreased with increasing diameter. The 1-inch disk samples averaged 23 percent bark while the 8-inch samples had an average 12 percent bark.

USE OF RESULTS

The information in table 1 can be used for estimating green or oven-dry weights of individual trees (or portions of trees) and stands growing on the better upland oak sites. Use of the conversion factors at the bottom of table 1 allows prediction in metric terms.

The only tree measurement needed for prediction is dbh. For instance, a 7-inch dbh hardwood tree would weigh 496 pounds green, or 292 pounds dry: the portions larger than 3 inches d.o.b. would weigh 406 pounds green or 239 pounds dry; the portions 3 inches d.o.b. and smaller would weigh 90 pounds green or 53 pounds dry.

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Wartluft, Jeffrey L.
1977. **Weights of small Appalachian hardwood trees and components.**
Northeast. For. Exp. Stn., Upper Darby, Pa.
4 p., illus. (USDA For. Serv. Res. Pap. NE-366)

Whole-tree weights, green and oven-dry, are shown in tables for Appalachian hardwood trees 1 to 10 inches dbh. Weights are also divided into tree portions greater than 3 inches and less than or equal to 3 inches in diameter. Information on species, moisture content, and percent bark accompany the weights. And metric conversions are provided.

KEYWORDS: Tree weight, Appalachian hardwoods, biomass.

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STRIP CLEARCUTTING DID NOT DEGRADE THE SITE IN A SPRUCE-FIR FOREST IN CENTRAL MAINE

by Miroslaw M. Czapowskyj, Robert V. Rourke, and Robert M. Frank

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ABSTRACT

Changes in the nutrient concentration in the forest floor and in the mineral soil were assessed on a mature spruce-fir stand in central Maine that had been harvested in 1965 by strip clearcutting. On part of the site, slash was left in place; on other parts it was removed, and on some it was burned. Eight years after the harvest, the clearcut areas tended to have increased pH and increased concentrations of bases and percentages of base saturation, but the amounts of N and P were comparable to those in the residual forest. Soil drainage class and differences in parent material were the major sources of variation. There were no significant differences between control and slash-disposal treatments or among treatments. There was no evidence of site degradation from strip clearcutting.

Keywords: spruce-fir, effects of strip clearcutting, nutrient concentration, forest floor

FOREST HARVESTING, particularly large-scale logging operations, may exert an impact on soil nutrients and fertility-related site characteristics. To culture a new stand that is physiologically healthy, it is important that the nutrient budget be assessed. If excessive amounts of nutrients have been removed by stand harvesting, corrective measures may be essential.

Recent studies on this subject have been conducted for mixed hardwoods *(Boyle and Ek 1972; Boyle et al. 1973)*, and the nutrient budget for a spruce-fir forest in Quebec was estimated by Weetman and Webber *(1972)*. However, our knowledge of nutrient budget for spruce-fir sites in Maine is not extensive. Young and Guinn *(1966)* and Young and Carpenter *(1967)* presented data on nutrient concentrations in wood, branches, bark, roots, and foilage of the major species. These data provide a basis for estimating nutrient budgets and for evaluating possible nutrient losses due to timber harvesting. The first attempt to estimate a nutrient budget for a softwood forest type in west-central Maine was made by Norton and Young *(1976)*.

There is no information about the effects of clearcutting spruce-fir forests on Maine soils. Because of rapid changes in silvicultural practices such as complete stand removal and the change from shortwood to full-tree logging, more and more biomass is being removed from the forest. Also, previously unusable species are now being used and different sizes and qualities of timber are now being marketed. Currently, large areas of spruce-fir forests are infested by the spruce budworm *(Choristoneura fumiferana* (Clem.)) and are being salvaged to reduce losses. Thus depletion of soil nutrients and possible site degradation is a cause for concern. A study on the Hubbard Brook Experimental Forest *(Likens et al. 1967)* and a report on the effects of whole-tree harvesting of eastern cottonwood *(Populus deltoides* Bartr.) in Alabama *(White)* support this concern.

However assessments of nutrients in soils, as related to clearcutting and slash-disposal method, are not extensive. In this paper we present data on nutrient concentrations (and related characteristics) of soils in central Maine on a residual and strip-harvested forest site that was primarily softwood.

STUDY AREA

A mature spruce-fir stand in the Penobscot Experimental Forest, Bradley, Maine, was harvested by strip clearcutting in 1965. The slash was either left in place, or removed, or burned. Eight years later we estimated the nutrient concentration both in the forest floor and in clearcut areas.

The Forest

Original stand.—The original stand was a spruce-fir type on a site that was primarily softwood; the major age class was 70 to 80 years. The height of dominant trees ranged from 11 to 17 m, and the average diameter of merchantable stock was about 18 cm. Initial volume totaled 130 m^3/ha in trees 11.4 cm in diameter at breast height (dbh) or larger. Fifty percent of this volume was white spruce (*Picea glauca* (Moench) Voss), red spruce (*P. rubens* Sarg.), and balsam fir (*Abies balsamea* (L.) Mill.); 25 percent was hardwoods; 10 percent each was eastern hemlock (*Tsuga canadensis* (L.) Carr.) and eastern white pine (*Pinus strobus* L.); and 5 percent was northern white-cedar, (*Thuja occidentalis* L.).

Strip-Harvest and Slash Disposal.—All trees 1.34 m in height or larger were felled. Only merchantable wood was removed from plots where slash was to be burned or left in place. On plots where slash was to be removed, full trees (bole and branches) that were 1.34 m in height or larger were removed by skidding. Strip harvesting began in the fall of 1964 and was completed by the spring of 1965. Slash burning was done in August 1965.

Regeneration of Clearcut Strips.—Eight years after the cutting and slash treatments, all plots had well-established and well-distributed reproduction. There were more than 90,000 stems per hectare—two-thirds were 15.2 cm in height or larger and were considered established. The percentage of established seedlings was slightly greater on moderately well-drained and well-drained soils than it was on wetter soils. About 30 percent of the stems were spruce-fir; the remainder were primarily pioneer hardwoods. Plots where slash was left in place had the highest proportion of spruce-fir stems; plots where the slash was removed or burned had the lowest.

Soils

Elevations ranged from 37 to 43 m; there are complexes of well-drained to poorly drained soils on glacial till and moderately well-drained to poorly drained soils on marine sediments. The soils form an intricate pattern upon the landscape; on marine sediments they include Elmwood, Buxton, and Scantic. These soils are in low, nearly level positions, and abut the soils on glacial till; the latter include Marlow, Peru, and Monarda soils that are found on the slopes and small knolls. Soils are classified as Inceptisols or Spodosols

Forest Floor.—The forest floor was composed of dead residues of plant and animal kingdoms consisting of 01 and 02 soil layers, and living organisms, woody plants, herbs, grasses, and mosses. The forest floor in the residual forest was derived primarily from conifer needles and twigs. In clearcut areas, the forest floor also included hardwood and shrub foilage. This reflects the abundance of pioneer hardwood regeneration. Contributions to the forest floor by the different sources were not separated.

Mineral Soil.—Soil texture reflects the parent material. Nonstony silt loam surfaces above silty clay loam subsurfaces predominated in the marine sediments. There are also small areas that have a fine sandy loam surface above silty clay loam subsoil. In the stony glacial till, gravelly silt loams and loams extend to depths of 1.0 to 1.2 m or deeper unless restricted by bedrock. In some instances the subsoil is coarser as depth increases; it grades from a gravelly loam to a gravelly fine sandy loam.

Soil depth for rooting is 40 cm in the marine sediments and 40 to 60 cm in glacial till. Root penetration is restricted by a dense layer in the marine sediments and deep glacial till. This dense layer impedes water movement and contributes to the overall wet soil that is characteristic of the area. The resulting perched water table presents a barrier to root growth when it persists for extended periods.

METHODS

Strips about 40.0 and 60.0 m wide were harvested, leaving a 40.0-m wide alternate strip of residual forest; all strips were oriented east-west. We used a fixed grid of permanent regeneration sample plots at transects of 6 and 42 m from the northern forested edge. In the center of the residual strips, a similar line was used as a guide for sampling.

Field Procedure

We determined soil drainage from auger borings; there were three drainage classes: poorly drained, moderately well drained and well drained. We took core samples from the forest floor and from the mineral soil with a Uhland sampler.[1] We removed disturbed samples from the 01 and 02 horizons of the forest floor. We took samples from the upper 16 cm of the mineral soil, and included any genetic horizon that was present in this zone. The thickness of the forest floor was measured at several points and averaged to the nearest millimeter. A total of 88 points were sampled.

Laboratory Procedure

The core samples of the forest floor and mineral soils were dried to a constant weight and weighed to the nearest 0.1g. The quantities of the forest floor and of mineral soil per unit area, and their respective bulk densities, were calculated from ovendry core samples. The bulk density (Db) of the mineral soil was not corrected for stone content.

Air dried disturbed samples of the forest floor were ground in a Wiley mill to pass a 20-mesh screen, subsampled, and stored for analysis. Air-dried disturbed samples of mineral soil were passed through a 2-mm sieve and stored.

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[1] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. It does not constitute an official endorsement or approval by the Forest Service or the U.S. Department of Agriculture.

Chemical Analysis.—In analyzing the air-dried materials, we used a Beckman pH meter to measure the pH, in a 1:1 (soil:water) aqueous solution for mineral soil, and in a 1:4 (organic:water) solution for forest floor materials. We determined exchange acidity by the method outlined by Adams and Evans *(1962)*; exchangeable cations were extracted with a neutral $1N$ NH_4OAc and determined with a Jarrel-Ash atomic absorption spectrophotometer. The extracts used for the analyses of Ca and Mg were prepared to contain 0.1 percent of La. Cation exchange capacity (CEC) was determined by adding the exchange acidity and exchangeable bases. Phosphorus was extracted with $0.05N$ HC1 + $0.025N$ H_2SO_4; it was determined colorimetrically by use of the molybdate-vanadate solution described by Nelson and others *(1953)*. The extracts were clarified with carbon black before being determined. We used the Kjeldahl method to determine total nitrogen.

Organic matter in both the forest floor and the mineral soil was determined by loss on ignition at >500°C. Carbon was calculated from the percentage of loss on ignition; we used a conversion factor of 0.58.

Statistical Analysis.—The data were tabulated by soil drainage class and by slash disposal method. The data in this study were multivariate, and multivariate procedures were used to analyze the results. We used a simultaneous test procedure (STP) to test the hypothesis that there were no differences among treatments. (Simultaneous test procedures in multivariate analysis of variance are discussed by Gabriel *(1968)*). The STP is based on the maximum characteristic root statistic (θ) The critical value of θ depends on the fact that there are four treatments; and that 19 forest floor variables and 16 mineral soil variables were measured. (The Db was not included.) The significance level in an STP is said to be experimentwise rather than testwise.

The first step of the analysis was to determine the variables that best characterized the differences among the treatments. We used a stepwise discriminate analysis *(Dixon, 1975)*. The best discriminating variables were those with the largest mean squared differences among treatments.

Separate analyses were performed on forest floor and mineral soil variables for each soil drainage class. Variables were included in the stepwise analyses if the variance ratio (F) exceeded the critial value of the (F) Distribution with appropriate degrees of freedom.

RESULTS AND DISCUSSION

Mean values for the 19 forest floor variables are presented in table 1 and those for the 17 mineral soil variables in table 3. The data show considerable variability in all characteristics. Some variables followed certain patterns according to soil drainage class or slash disposal method; others followed no particular pattern.

Variance ratios for comparisons of pairs of treatments and the best variable for discriminating among the treatments are given for forest floor variables in table 2, and for mineral soil variables in table 4.

Forest Floor

On poorly drained and moderately well-drained soils, the percentage of base saturation was the best variable for discriminating between control plots (undisturbed forest) and the three slash-disposal treatments. The percentage of base saturation was consistently higher on strip-clearcut areas than it was on the undisturbed forest. The percentage of base saturation also was higher on plots where slash was left in place and on those where it was burned. Comparisons between the three slash treatments showed that the percentage of base saturation was significantly higher on plots where slash was left in place and on plots where it was burned than it was on plots where slash was removed.

On poorly drained soils, two other variables with high variance ratios, pH (F = 3.78) and exchangeable Mg (F = 3.76), could also be used to discriminate among the treatments. Both pH and Mg were correlated with the percentage of base saturation (r = 0.91 and 0.77, respectively).

On moderately well drained soils, there were significant increases in the percentage of base saturation on plots where slash was left or removed compared to the control plots.

On well-drained soils, pH was the best dis-

Table 1.—Means of forest floor properties, by soil drainage class and slash disposal method

Forest floor properties	Poorly drained				Moderately well drained				Well drained			
		Slash disposal				Slash disposal				Slash disposal		
	Control	Left	Removed	Burned	Control	Left	Removed	Burned	Control	Left	Removed	Burned
Thickness (cm)	9.6	9.7	14.5	10.2	6.6	6.4	5.3	7.1	5.3	7.2	7.4	5.8
Bulk density (g/cc)	0.10	0.10	0.09	0.12	0.19	0.16	0.17	0.14	0.22	0.13	0.14	0.19
Ovendry weight (kg/m²)	9.6	9.0	8.7	10.7	12.4	10.0	8.1	9.4	11.4	9.3	10.5	10.6
Volatile matter (kg/m²)	8.1	6.6	6.6	7.9	9.6	6.7	5.3	6.8	9.4	7.6	7.9	8.1
Nitrogen (%)	1.34	1.61	1.38	1.43	1.38	1.27	1.00	1.25	1.23	1.46	1.33	1.27
Phosphorus (ppm)	37.3	39.1	27.5	41.9	50.0	62.7	42.4	57.3	66.2	68.4	67.8	64.1
Calcium (meq/100g)	26.0	46.0	31.6	42.7	22.5	28.2	31.8	24.9	21.1	23.8	26.5	25.8
Magnesium (meq/100g)	4.4	7.1	5.1	5.4	2.6	4.6	4.1	4.1	3.0	3.3	4.2	5.1
Potassium (meq/100g)	1.7	2.8	1.8	2.0	1.8	2.8	2.1	1.9	2.2	3.1	2.9	2.7
Sodium (meq/100g)	0.2	0.4	0.3	0.3	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Exchange acidity (meq/100g)	68.6	47.1	53.3	49.7	64.4	47.6	41.5	50.0	66.4	61.2	55.9	53.9
CEC (meq/100g)	100.9	103.5	92.1	100.0	91.4	83.4	79.7	81.1	92.8	91.7	89.7	87.7
Total bases (meq/100g)	32.3	56.4	38.8	50.3	27.0	35.8	38.1	31.1	26.4	30.4	33.8	33.7
Base saturation (%)	31.9	53.6	40.8	49.9	30.3	43.0	48.0	38.0	28.5	32.8	37.2	38.7
Zinc (ppm)	11.8	11.8	10.3	11.1	7.2	16.1	11.6	11.1	10.5	14.0	14.0	12.6
Iron (ppm)	14.7	9.2	12.1	9.9	13.5	17.4	16.8	14.2	10.5	17.7	14.0	13.3
Manganese (ppm)	101.4	135.0	101.4	245.3	353.0	400.0	350.7	409.2	149.2	240.6	251.1	498.9
C/N ratio	35.9	27.9	33.9	30.2	32.3	32.0	35.6	32.7	38.5	33.2	33.2	35.7
pH	4.1	5.0	4.6	4.7	3.9	4.4	4.6	4.3	3.8	4.0	4.1	4.3
Number of samples	7	14	13	17	3	6	5	6	4	5	5	3

Table 2.—Forest floor variance ratios for comparisons of slash-disposal treatments, by soil drainage class, and the best discriminating variable among treatments.

Treatment	Poorly drained	Moderately well drained	Well drained
		F ratio	
Control vs. slash left	14.84**	4.53*	3.44
Control vs. slash removed	2.48	8.27*	6.83*
Control vs. slash burned	10.86**	1.66	12.20**
Slash left vs. slash removed	7.36**	0.96	0.65
Slash left vs. slash burned	0.70	1.06	3.80
Slash removed vs. slash burned	4.06*	3.85	1.57
Among treatments	6.30**	3.12	4.45*
Best discriminating variable	Base saturation	Base saturation	pH

*Significant at the 0.05 level; **significant at the 0.01 level. (Based on F distribution.)

criminating variable. The pH values were significantly higher on plots where slash was removed or burned than they were on the undisturbed forest.

Base saturation was the best discriminator among treatments for forest floor variables on poorly drained soils (F = 6.30), and on moderately well-drained soils (F = 3.12). On well-drained soils, pH (F = 4.45) was the best discriminator.

Because the forest floor is an important source of nutrients for tree growth—and influences physical characteristics of soil—it has received considerable attention in recent years. Studies on this subject have been made by Mader *(1953);* McFee and Stone *(1965);* Stutzbach and others *(1972);* and Wollum *(1973).* So certain comparative values are available.

We found that thickness decreased slightly as soil drainage improved (poorly drained to well drained); the values for clearcut areas were somewhat higher than they were in the undisturbed forest. The range of thickness in the undisturbed forest approximates earlier estimates by Lull *(1959)*. The Db was lowest on poorly drained soils and remained the same in residual and clearcut areas, but it decreased on clearcut areas of moderately well-drained and well-drained soils compared to the undisturbed forest. A mean Db of 0.15 g/cm^3 approximates the values reported by McFee and Stone *(1965)* for a yellow birch - red spruce forest in the Adirondacks. The range of ovendry weight was 9.6 to 12.4 kg/m^2 in the undisturbed forest, and 8.1 to 10.7 kg/m^2 in clearcut areas. The differences were not consistent for soil drainage class or slash disposal method.

The weight of volatile matter tended to increase as soil drainage improved, and was consistently lower on clearcut areas. This weight correlated positively (r = 0.87) with ovendry weight.

By contrast, Wollum *(1973)* reported ranges of 0.9 to 8.1 kg/m^2 for ovendry weight, and 0.5 to

Table 3.—Means of mineral soil properties, by soil drainage class and slash disposal method

Mineral soil properties	Poorly drained				Moderately well drained				Well drained			
		Slash disposal				Slash disposal				Slash disposal		
	Control	Left	Removed	Burned	Control	Left	Removed	Burned	Control	Left	Removed	Burned
Bulk density (g/cc)	1.6	1.5	1.3	1.4	1.0	1.1	1.1	1.2	1.0	1.1	1.0	1.0
Organic matter (%)	5.7	7.0	8.9	7.7	7.3	6.5	8.4	6.8	8.2	9.0	9.2	7.7
Nitrogen (%)	0.19	0.21	0.26	0.22	0.23	0.16	0.20	0.16	0.16	0.21	0.21	0.14
Phosphorus (ppm)	3.2	6.2	4.8	4.0	5.1	7.9	5.0	12.0	5.5	0.8	6.8	3.8
Calcium (meq/100g)	3.0	8.3	5.2	5.7	0.9	1.2	2.9	0.8	1.1	1.2	1.6	0.9
Magnesium (meq/100g)	0.6	1.3	1.0	0.8	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Potassium (meq/100g)	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sodium (meq/100g)	<0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Exchange acidity (meq/100g)	9.3	8.4	12.4	10.2	12.7	10.5	11.9	11.5	11.7	12.5	15.0	13.1
CEC (meq/100g)	13.0	18.2	18.8	16.9	13.8	12.1	15.3	12.6	13.1	14.0	16.9	14.3
Total bases (meq/100g)	3.7	9.9	6.4	6.7	1.1	1.5	3.4	1.1	1.4	1.5	1.9	1.2
Base saturation (%)	22.9	50.9	32.1	35.3	7.7	12.8	22.6	8.7	10.2	11.8	12.2	8.0
Zinc (ppm)	3.0	2.3	2.4	1.9	5.6	2.3	1.8	1.3	2.0	1.9	3.2	1.0
Iron (ppm)	4.1	1.1	3.2	3.1	12.5	5.8	10.3	5.5	14.3	12.6	21.6	14.7
Manganese (ppm)	3.3	3.8	10.8	10.8	1.5	4.7	11.4	5.2	3.3	2.3	6.8	6.8
C/N ratio	18.4	18.6	20.9	20.8	19.0	24.2	26.2	23.8	29.8	26.2	25.0	30.7
pH	4.9	5.6	5.1	5.0	4.5	5.0	5.0	4.8	4.8	5.0	4.7	4.7
Number of samples	7	14	13	17	3	6	5	6	4	5	5	3

Table 4.—Mineral soil variance ratios for comparisons of slash-disposal treatments, by soil drainage class, and the best discriminating variable among treatments.

Treatment	Poorly drained	Moderately well drained	Well drained
		F ratio	
Control vs. slash left	11.30**	0.13	—
Control vs. slash removed	0.90	9.05**	—
Control vs. slash burned	0.85	0.08	—
Slash left vs. slash removed	8.32**	10.28**	—
Slash left vs. slash burned	10.32**	0.62	—
Slash removed vs. slash burned	0.01	15.68**	—
Among treatments	5.30**	6.12*	—
Best discriminating variable	pH	Ca++	None

*Significant at the 0.05 level; **significant at the 0.01 level. (Based on F distribution.)

4.7 kg/m^2 for volatile matter, in an arid region in southern New Mexico. Youngberg *(1966)* reported ranges of 2.3 to 8.6 kg/m^2 for ovendry weight, and 1.6 to 6.9 kg/m^2 for volatile matter, on a Douglas-fir forest in the humid region of the Pacific Northwest.

Concentrations of Ca, Mg and K were consistently higher on clearcut areas than they were on the undistrubed forest; the increase in Ca ranged from 3 percent of total CEC on well-drained soils to 19 percent on poorly drained soils. The range of increase in Mg was 0 to 3 percent, for K it was 0 to 1 percent.

The Ca concentration tended to decrease as the soil drainage improved; concentration for Mg and K were inconsistent for soil drainage class or slash disposal method.

The exchange acidity was composed of exchangeable H and A1. Contributions by either source were not separated, but a study by Hoyle *(1973)* showed that the concentration of A1 exceeded that of H. Acidity was high and stable for all soil drainage classes and slash treatments: It was consistently higher in the residual forest floor and was primarily from coniferous needles. The forest floor of well-drained soils had the highest average values for all treatments. The variations were not related to any slash treatment.

The mean values for CEC were slightly lower on clearcut areas, but increased as the sites became wetter.

The N data show that there were no drastic changes due to clearcutting. Only slight increases were observed on clearcut areas of poorly drained and well-drained soils. On moderately well-drained soils this pattern was reversed. N values were consistently higher on plots where slash was left in place. The data correlated weakly with ovendry weight and volatile matter.

Extractable P was little affected by stand harvesting. Differences among slash disposal methods were inconsistent, but the lowest values were observed on plots of poorly drained and moderately well-drained soil where slash was removed. The average Fe concentration was highest on moderately well-drained sites but the concentration was inconsistent between treatments. The Zn concentration increased as soil drainage improved from poorly drained to well drained. The Mn concentration in the forest floor was high because of the high contents of Mn in spruce-fir-hemlock needles. Since a high Mn level may be toxic to plant growth, it would be desirable to establish what levels of Mn are critical.

None of the F ratios was significant at the 0.05 experimentwise level.

Mineral Soil

There were differences in the physical and chemical characteristics of surface mineral soil (table 3). Some differences reflected patterns similar to those shown by forest floor variables; others did not.

The pH values on poorly drained soils and the Ca++ concentrations on moderately well-drained soils were the best variables for discriminating between control plots and slash treatments (table 4). On well-drained soils, none of the variables was distinctive.

On poorly drained soils, pH values were significantly higher on plots where slash was left in place than they were on control plots or on plots where slash was burned or removed (table 3). The differences in pH on poorly drained soils and in Ca++ concentrations on moderately well-drained soils were also significant among the treatments. Again, variance ratios were not significant at the 0.05 experimentwise level.

The levels of Ca and Mg tended to parallel each other closely; both were strongly related to soil drainage. On clearcut areas, Ca and Mg levels were considerably higher on poorly drained soils than they were on moderately well-drained and well-drained soils. The parent material of the soil may be the main source of these variations. Marine deposits predominated on poorly drained sites. The lower level of these cations is attributable to differences in parent material and to more intensive leaching on moderately well-drained and well-drained glacial till. Similar trends have been reported by Hoyle *(1973)* and Wollum *(1973)*. The differences in K levels were less conspicuous.

Clearcut areas contained more exchangeable Ca and Mg. The effects of slash disposal methods were inconsistent.

The exchange acidity of the soil in clearcut areas for all drainage classes was highest where slash was removed and lowest where slash was left in place. This implies that, within clearcut areas, slash removal contributed to increased exchange acidity that did not result in a decrease in pH. Sites where slash was removed also showed a higher CEC than those that received other treatments.

Data on N indicated that there were no drastic changes due to clearcutting. We observed marked increases in N, primarily in the mineral fraction on poorly drained sites, and decreases on moderately well-drained sites. Losses of N due to slash burning were minor.

Extractable P was little affected by stand removal and the differences were inconsistent.

The average Zn and Fe levels increased as drainage class became drier. The Mn concentration was inconsistent between drainage classes.

Differences in Db between poorly drained and moderately well-drained and well-drained soils are partially explained by differences in the parent material of the soil. Quantities of organic matter (the percentage of loss on ignition) differed only slightly from one soil to another. The carbon-nitrogen ratios, relatively high and stable, show that the organic matter fraction of the soil was resistant to decomposition. The C/N ratio was in the order of poorly drained < moderately well-drained < well-drained soils. This possibly reflects greater microbial activity on the better drained soils, perhaps because of increased temperature, and better aeration.

SUMMARY AND CONCLUSIONS

From our assessment of some of the physical and chemical characteristics of spruce-fir sites eight years after strip clearcutting, we concluded that:

1. Strip clearcutting of the stand resulted in the alteration of certain characteristics in the forest floor and in the surface mineral soil
2. Natural soil drainage conditions were the major source of variation
3. The influence of clearcutting on the forest floor was distinct in the increase in the percentage of base saturation on poorly drained and moderately well-drained soils, and the increase in pH on well-drained soils
4. The effect of the clearcutting on the mineral soil was distinct in the increase in pH on poorly drained soil, and in Ca++ on moderately well-drained soil
5. The differences in chemical and physical properties of the forest floor and mineral soils among treatments could have been due to chance. None of the F ratios were significant at the 0.05 experimentwise level.

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Czapowskyj, Miroslaw M., Robert V. Rourke, and Robert M. Frank
1977. **Strip clearcutting did not degrade the site in a spruce-fir forest in central Maine.** Northeast For. Exp. Stn., Upper Darby, Pa.
8 p. (USDA For. Serv. Res. Pap. NE-367)

Changes in nutrient concentration in the forest floor and in the mineral soil were assessed on a mature spruce-fir stand in central Maine that had been harvested in 1965 by strip clearcutting. On part of the site, slash was left in place; on other parts it was removed, and on some it was burned. Eight years after the harvest, the clearcut areas tended to have increased pH and increased concentrations of bases and percentages of base saturation, but the amounts of N and P were comparable to those in the residual forest. Soil drainage class and differences in parent material were the major sources of variation. There were no significant differences between control and slash-disposal treatments or among treatments. There was no evidence of site degradation from strip clearcutting.

114:22:221.1

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THE MOBILE BARK BLOWER: AN EVALUATION OF PERFORMANCE AND COSTS

by Raymond L. Sarles and David M. Emanuel

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THE MOBILE BARK BLOWER: AN EVALUATION OF PERFORMANCE AND COSTS

ABSTRACT

A custom-built bark blower truck (MOBLOW) developed in Oregon was tested for its effectiveness in applying bark mulches, sawdust, and shavings in the eastern United States. Tests determined the bark blower's performance and cost in mulching grass-legume seedings and shrub beds with 10 bark products or wood residues. Bark blower trucks built to MOBLOW specifications can effectively apply pine and hardwood bark products, sawdust, and wood shavings, but cannot handle unprocessed bark residues. Blower trucks can be used to blow shredded bark, sawdust, and shavings into barns, cattle sheds, poultry houses, show rings, and corrals, and to deliver hogged fuel.

Keywords: Wood residue utilization, bark products, mulching equipment, erosion control, revegetation, animal bedding, hogged fuel.

THE INCREASING USE of wood and bark residues has resulted in a need for specialized equipment to process, transport, and deliver these materials. Studies have shown that there is a critical need for such equipment to apply shredded bark mulch more efficiently over grass-legume seedings on highway roadsides and surface mines *(Sarles and Emanuel 1976; Yocom and others 1971)*.

The horticultural market for bark products depends heavily on the availability and price of polyethylene bags; most of the bark industry's product is packaged and shipped to market in them. Made from petroleum, the bags have nearly doubled in price since 1973 and cost one-fourth to one-third of the wholesale price of bark, f.o.b. plant. Obviously, an efficient bulk-delivery system could improve the marketing of horticultural bark and other bark products, and help lower bark prices.

Several years ago, a special blower truck for delivering sawdust in bulk to fuel customers was developed by Rexius Fuel Service, Eugene, Oregon.[1] Today, that firm uses a fleet of improved blower trucks to transport, deliver, and apply horticultural bark products, sawdust, shavings, and organic soil conditioners *(Rexius 1971)*. Such equipment is virtually unknown in the eastern United States.

After seeing the blower trucks operate, we concluded that the machine could be used in the East and that it might help enlarge the market and increase sales of bark mulch, soil conditioners, and other wood residues. Landscape contractors might use the bark blower truck to deliver bulk quantities of bark and blow it on shrub beds and gardens, and seeding contractors might use the truck to deliver and blow large volumes of shredded bark mulch over roadside and surface-mine seedings.

This unit might also be used to apply shredded bark, sawdust, and shavings in barns, cattle sheds, poultry houses, show rings, and corrals, and to deliver hogged fuel to customers who fire furnaces and boilers with wood residues.

To find out how well blower trucks can handle and apply hardwood and pine barks and wood residues in the East, the Forest Products Marketing Laboratory purchased one for testing.

THE MOBILE BARK BLOWER

The mobile bark blower (MOBLOW) is a custom-built truck designed for dumping and blowing wood residues and bark products (fig. 1). Though specially built, its components are standard and readily available (Appendix). MOBLOW includes a cab and chassis with tandem rear axle; two power take-offs; a 30-cubic-yard truck box with a hydraulically-operated front bulkhead and top-mounted rear door; a high-pressure rotary blower; a rotary airlock with injector tee; a hydraulic system consisting of an oil reservoir, a pump, two orbital motors, and controls at two positions; and ten 12-foot lengths of 4-inch flexible metal hose fitted with quick couplers (fig. 2).

MOBLOW is versatile and can transport a large volume of bulky, low-density materials; dump any or all of its load, with full control when the moveable front bulkhead is advanced; and blow bark mulches, soil conditioners, sawdust, and shavings up to 125 feet from the truck through coupled lengths of hose. A two-man crew can perform these operations. One operates the blower, bulkhead, and airlock controls (from the rear control panel), and feeds material into the rotary airlock; the other handles the hoses and directs the stream.

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[1] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the Forest Service or the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

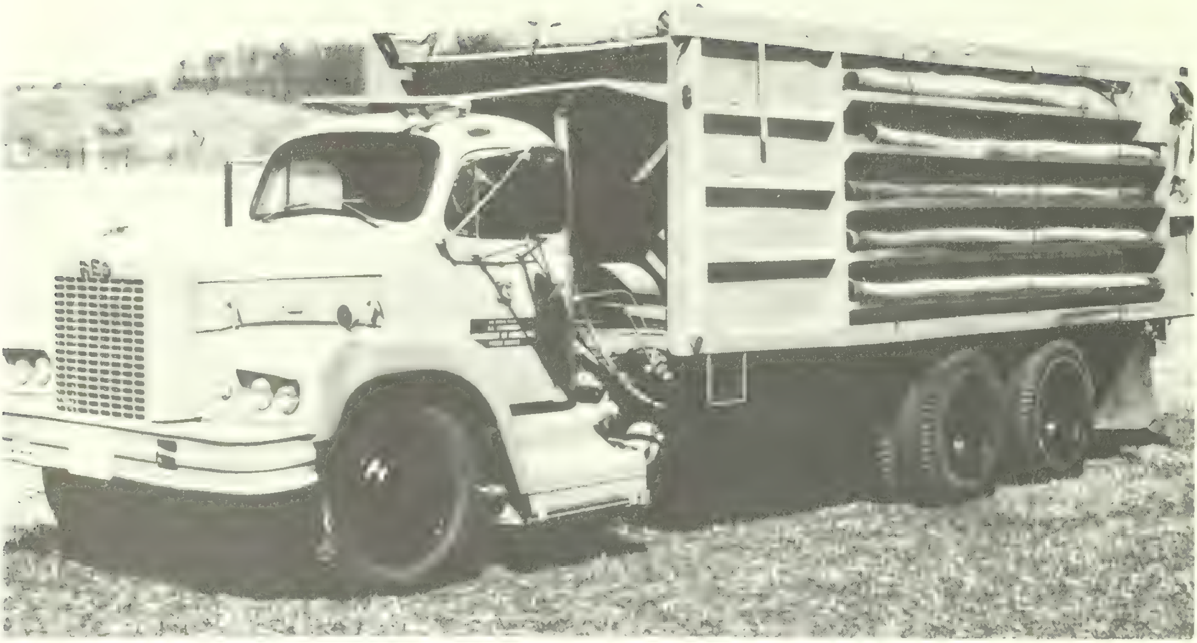


Figure 1.—The mobile bark blower (MOBLOW) is a heavy-duty, large-capacity truck equipped with special machinery for dumping and blowing wood residues and bark products.

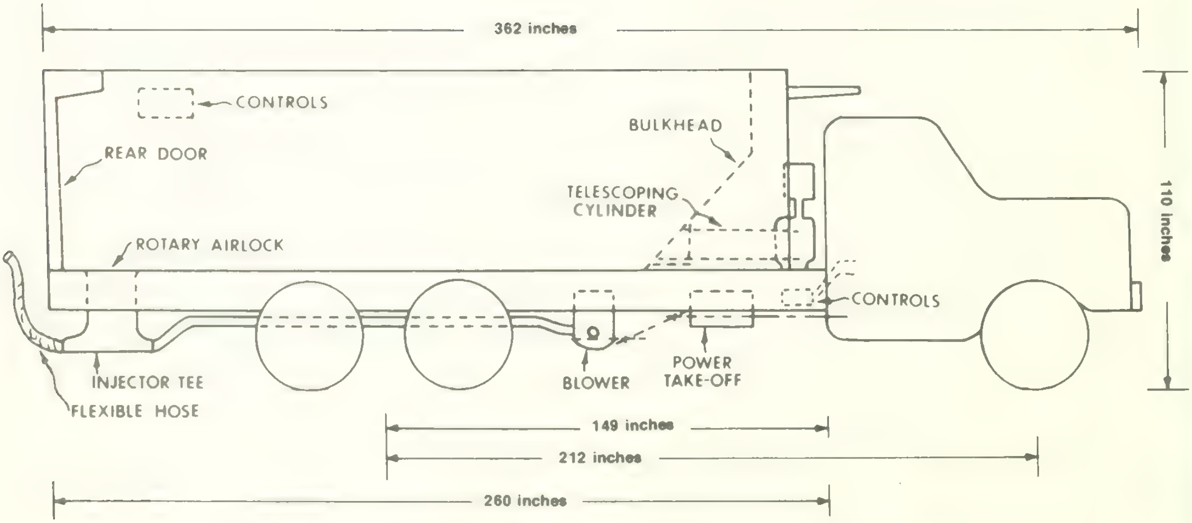


Figure 2.—MOBLOW dimensions and special machinery.

STUDY METHODS

The study was conducted in four parts: (1) blowing trials of 10 bark products or wood residues; (2) application of shredded bark on two mulching jobs; (3) determination of application rates; and (4) estimation of mulching costs.

Blowing trials.—A large variety of bark products and wood residues are available in the East for landscaping, erosion control, and animal bedding. Our blowing trials determined which ones could be fed into the rotary airlock, metered into a high-pressure air stream, and blown through the hoses.

Because of the interest in shredded hardwood barks for erosion control and revegetation, we tested bark mulches from four processors. Pine barks are readily available in the East; we tested five grades that were obtained from two processors. We screened most materials to determine their distribution of particle sizes (by weight) (table 1).

Mulching trials.—In cooperation with the Roadside Development Division, West Virginia Department of Highways, and the Agronomy Department of Virginia Polytechnic Institute and State University, we mulched a grass seeding along U.S. 460 in Mercer County. We applied 25 cubic yards of bark mulch to this 3/4-acre seeding, which was a 2:1 fill slope, 125 feet long and 260 feet wide.

To mulch the slope as efficiently as possible, we positioned MOBLOW at the top and laid out 9 sections (108 feet) of hose to the bottom. The high-pressure air stream easily cast the bark 30 feet to the toe of the long slope. We worked our way up the slope, uncoupling two or three lengths of hose at a time, and mulched 30 feet to each side as we went. The result was about a 60-foot swath from top to bottom of the slope. We repeated this procedure five times to cover the entire site.

To develop production data, we timed the operation. Operating times were recorded as setup time, blowing time, and downtime. Setup time included positioning MOBLOW and laying out the hoses. This took 26 minutes. Blowing time totaled 124 minutes; and downtime, caused by mechanical breakdowns and plugged hoses, consumed 58 minutes. Overall, the average rate of application was 7.2 cubic yards of mulch per hour. For the five swaths mulched the rate ranged from 5 to 20 cubic yards per hour.

Our second mulching trial was conducted on a

Table 1.—Distribution of particle sizes of bark products and wood residues by percent of dry weight retained on screens

Material	Screen opening sizes (inches)							
	2	1	1/2	3/16	3/32	3/64	1/64	<1/64
Raw bark residues								
mixed hardwoods	6.1	3.6	8.1	24.4	19.1	12.2	14.3	12.2
white cedar	11.6	2.6	9.5	40.7	16.7	11.8	5.0	2.1
Fine hardwood residues								
fresh sawdust	—	—	4.3	4.3	10.4	38.8	34.6	7.6
dry planer shavings			no determination made					
Shredded hardwood bark mulch								
processor A	—	—	22.0	24.5	19.1	14.8	12.9	6.7
processor B	0.1	1.9	12.6	41.9	21.0	11.3	6.8	4.1
processor C	—	13.1	5.1	46.7	15.3	10.2	6.2	3.4
processor D	—	.8	5.1	29.0	18.1	18.4	19.5	9.1
Pine bark products								
shredded grade								
processor E	—	0.7	19.6	55.8	8.0	3.7	5.9	6.3
soil conditioner								
processor E	—	—	.1	25.2	28.8	20.9	15.6	9.4
processor F	—	—	—	.1	20.0	43.0	24.8	12.1
mulch grade								
processor F	—	—	1.1	41.2	33.2	10.7	6.2	7.6
mininugget grade			most particles 3/4 to 1-1/2 inches long					
nugget grade			most particles 1-1/2 to 2-1/2 inches long					

shrub bed. In cooperation with the Department of Highways and a landscape contractor, we used MOBLOW to apply shredded bark to a 1,500-square-foot shrub bed that was located on Interstate 77 in Jackson County, West Virginia. The bed had been planted with 160 balled and burlapped shrubs.

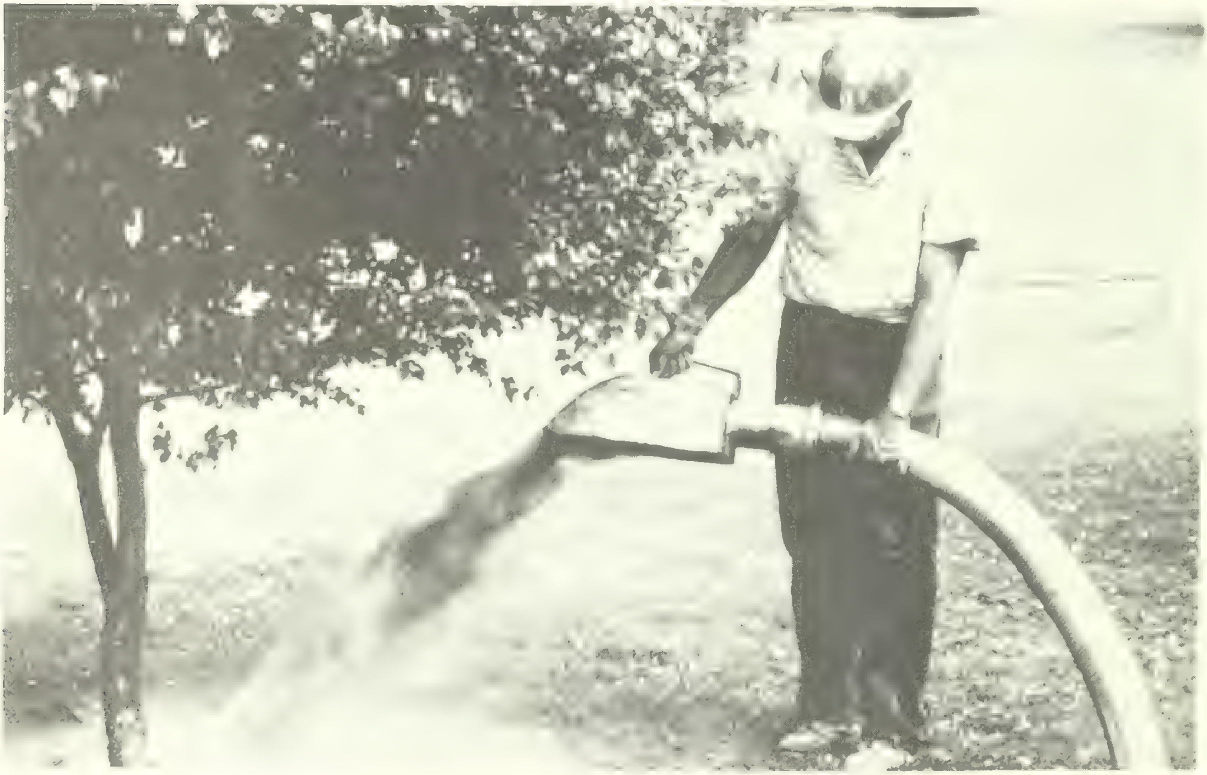
We mulched the entire bed with a 4-inch layer of bark—about 17 cubic yards—in two operations. MOBLOW was first positioned on the road about 70 feet above the shrub bed; eight lengths of hose were needed to reach the bed. Next, MOBLOW was positioned along the shrub bed so only two lengths of hose were needed. In the first operation, 70 shrubs were mulched with 8 cubic yards of bark in 68 minutes; this included setup time, blowing time, and 15 minutes of downtime caused by plugged feeder and hoses. In the second, 90 shrubs were mulched in 32 minutes with 9 cubic yards of bark. Rates of application for the two operations were 7 and 17 cubic yards per hour. Overall, the rate averaged 10 cubic yards per hour.

We mulched the shrub bed with and without the deflector hood (figs. 3, 4). The hood controlled mulch placement and minimized the impacting of bark particles against shrub stems. Mulch could be applied faster and blown farther without the deflector, but placement was less accurate.

Estimating mulching costs.—Many factors influence mulching costs. For this study we selected three major factors to develop a range of cost estimates for mulching seedings and shrub beds: (1) the cost of men and machines in mulching systems using MOBLOW; (2) the production rates of these systems; and (3) the amount of mulch applied per acre.

We planned two production systems, System I and System II. System I was designed for mulching large seedings on surface mines and along highways. Bark mulch is delivered in bulk quantities and stockpiled because of the distance of these jobs from supply yards. Thus a front-end loader and operator is required at the stockpile to load MOBLOW. System II, which was design-

Figure 3.—Fresh sawdust mulch is applied with the deflector hood.



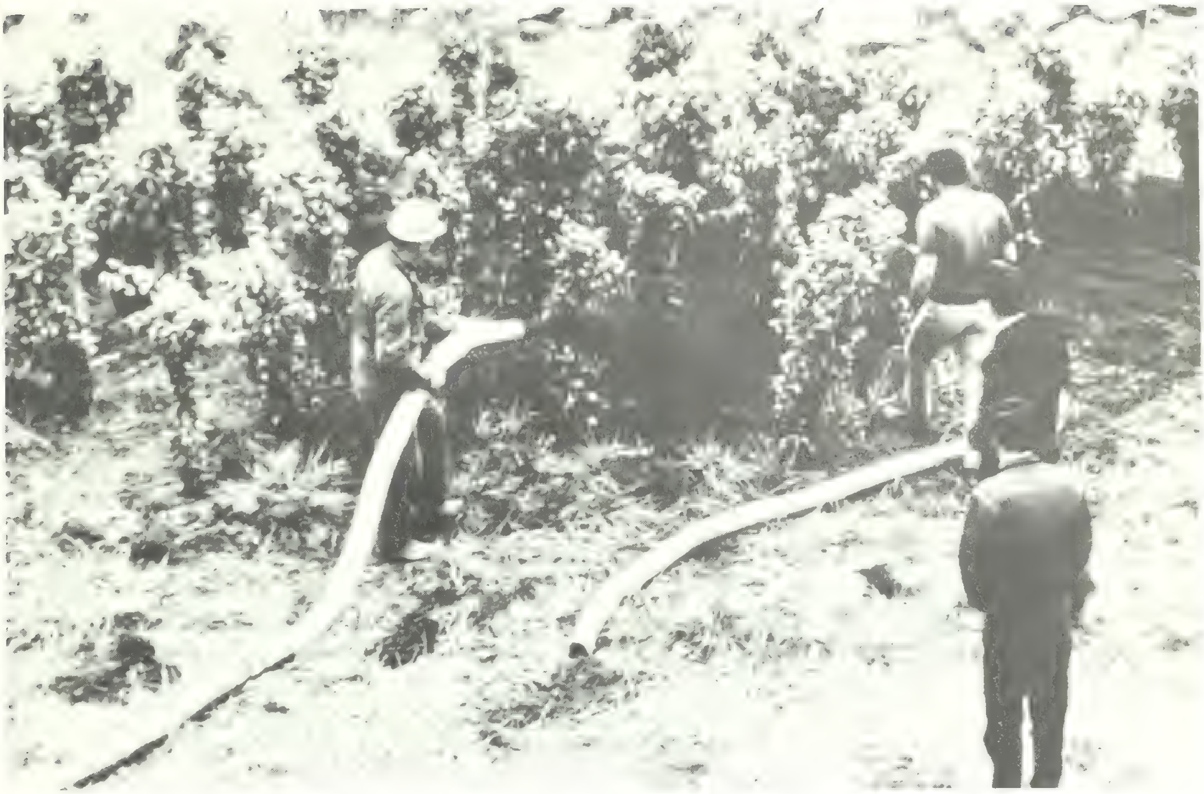


Figure 4.—Shredded hardwood bark mulch is applied without the deflector hood.

ed for mulching shrub beds, does not include a loader and operator because loading services for System II jobs usually are provided at the supply yard. Equipment and manpower requirements for these systems are:

System I *(Mulching seedings)*	System II *(Mulching shrub beds)*
MOBLOW	MOBLOW
+	+
End loader	Truck driver
+	+
Truck driver	Laborer
+	
Loader operator	
+	
Laborer	

In estimating labor costs for Systems I and II, we used the wage schedule for 1975 highway construction contracts in West Virginia. Estimates of equipment operating costs, based on 1,400 hours of use per year, were developed for three MOBLOW units and three front-end loaders. The MOBLOW trucks were: (1) a used unit that cost $20,000; (2) a new unit with a standard-duty cab and chassis at $45,000; and (3) a new unit with a heavy-duty cab and chassis at $60,000. The front-end loaders were: (1) a used industrial tractor with a 3/4-yard bucket at $5,000; (2) a similar but new tractor that cost $12,000; and (3) a new, construction loader with a 4-yard bucket at $30,000.

The production rates for Systems I and II were developed from MOBLOW application rates and loading times for the two sizes of front-end loaders. We assumed that the application rates recorded in both trials represented low, average, and high performance, so we used rates of 5, 8, and 18 cubic yards per hour. We used a loading time of 15 minutes for the big loader and 45 minutes for the small one.

The mulch rates selected for determining cost estimates were 30 and 50 cubic yards per acre for seedings, and 4 inches for shrub beds. These specifications follow the recommendations of Sarles and Emanuel *(1976)*.

RESULTS AND DISCUSSION

Materials testing.—Unprocessed bark residues (mixed hardwoods and white cedar) failed in blowing trials because splintery particles longer than 2 inches repeatedly plugged the hose sections.

Processed shredded barks—both hardwood and pine—were blown successfully despite occasional plugging. We concluded that when particles longer than 2 inches are screened out, these bark products can be used with MOBLOW. Success in blowing the shredded materials depends largely on the operator's skill in metering the material into the airlock.

Processed pine barks—nuggets, mininuggets, mulch, and soil conditioners—were all blown successfully. Except for the soil conditioners, these chunky and platy barks handled and blew easily and didn't plug the hoses. Because of their weight and shape, bark nuggets were blown 45 feet; but finer soil-conditioner particles, which look easy to blow, compacted in the hoses and the injector tee when fed too fast. This could have been avoided by more careful control of the feed rate.

Planer shavings were the easiest of all materials to feed and blow; they could be metered into the airlock as fast as the operator could work, and the system was never overloaded (fig.5).

Fresh hardwood sawdust also seemed easy to blow, but it frequently plugged the injector tee and the hoses. However the plugging was not caused by the sawdust but by the pieces and chunks of wood that were mixed with it. We

Figure 5.—MOBLOW handled dry, hardwood planer shavings exceptionally well; this material was blown as fast as it was fed into the system.

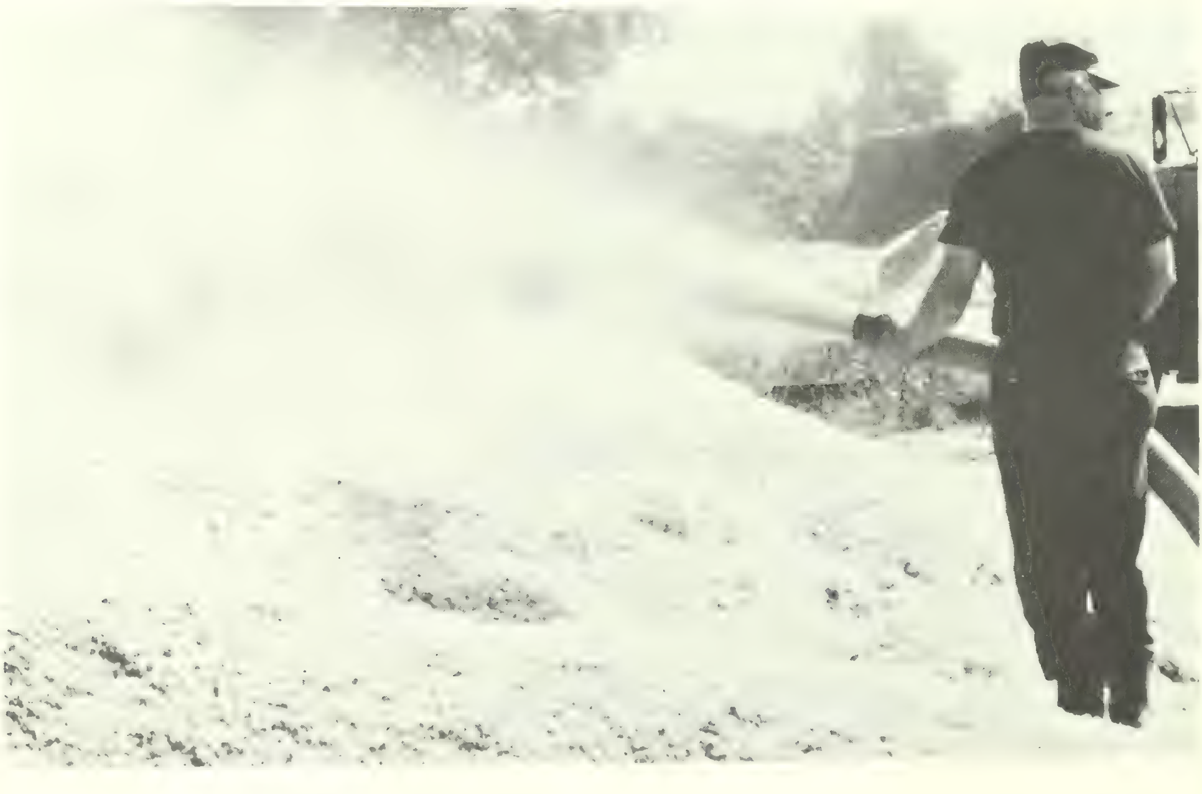


Table 2.—Acreage mulched per 8-hour day at 30 cubic yards of shredded bark mulch per acre by System I[a]

Application rate	Production rate (Loading times)		Increased production due to faster loading
	15 minutes	45 minutes	
yd^3/hr	*acres*		*percent*
5	1.28	1.19	8.0
8	2.00	1.78	12.0
18	4.17	3.31	26.0

[a] For application of 50 yd^3 acre, multiply acreages by 0.6.

tried to solve the problem by placing an expanded metal grate with 1-1/2-inch openings over the inlet of the rotary airlock. While the grate screened out the large pieces and prevented plugging, it hindered the feed rate so much that its use proved impractical. Fresh or dry sawdust, if free of chunks of wood and debris, can be blown easily (fig. 3).

Production rates.—Rates of production for mulching seedings and shrub beds vary because of site conditions, the experience of the crew, equipment, mulching specifications, and loading time. We included these factors in developing our estimates of production rates for Systems I and II. For example, site conditions, crew experience, and equipment are accounted for in the range of application rates that we developed from the mulching trials.

In the System I operation, the rate of application has a large effect on daily production; it is more significant than loading time. Still, loading time is important because it works together with application rate to produce proportionately greater increases in daily production, particularly at the higher application rates. For example, a crew that applies mulch at a rate of 18 cubic yards per hour can increase production by 26 percent when it uses a faster operating loader; at 5 cubic yards an hour the crew can increase production only by 8 percent (table 2).

Since the application rate greatly affects daily production, it is important to note that the two factors—the experience of the crew and reliability of equiment—can be managed for improvement. Crews can be trained, and MOBLOW machines can be maintained in good operating condition. Attention to both can probably double low production rates.

Table 3.—Production per 8-hour day at 4 inches of shredded bark mulch by System II[a]

Application rate	Daily production	
yd^3/hr	*yd^3*	*ft^2*
5	34	2,754
8	50	4,091
18	90	7,270

[a] Includes travel time of 1 hour for each trip to the supply yard.

Production rates for mulching shrub beds include a travel time of 1 hour for each trip to the supply yard to reload. By combining application rate and travel time, we found that MOBLOW and its crew could apply 34 to 90 cubic yards of shredded bark mulch per 8-hour day to a depth of 4 inches over shrub beds totaling 2,754 to 7,270 square feet (table 3).

Cost estimates.—We produced hourly operating costs for seven combinations of men and machines—four for System I and three for System II. For System I, hourly costs ranged from $36 an hour for used machines to $49 for new, heavy-duty machines. Depending on the cost of machinery, System II costs ranged from $25 to $30 per hour in West Virginia. These figures can be adjusted as costs change, or for other parts of the country (tables 4,5).

By combining hourly operating costs with production rates, we developed cost estimates for seedbed and shrub bed mulching (tables 4,5). It is obvious that mulching costs are affected more by the production rate than by hourly operating costs. So new or larger machines, or both, that perform at higher production rates than used or smaller machines, or both, can yield lower mulching costs than the "less expen-

Table 4.—Estimated cost of System I operations in dollars per acre at 30 cubic yards of shredded bark mulch per acre[a]

System I machines	Operating cost	Production rate (acres/8 hour day)			
		1	2	3	4
	dollars/hour	--------- *dollars/acre* ---------			
Used MOBLOW and used 3/4-yard loader	36	288	144	92	—
New MOBLOW and new 3/4-yard loader	40	320	160	107	—
Used MOBLOW and new 4-yard loader	43	—	172	115	86
New heavy-duty MOBLOW and new 4-yard loader	49	—	196	130	98

[a] For application of 50 yd^3/acre, multiply dollars per acre by 1.67.

Table 5.—Estimated unit cost of System II operations at 4 inches of shredded bark mulch on shrub beds

System II machines	Operating cost	Production rate (yd^3 or 100 ft^2/8-hour day)		
		30	60	90
	dollars/hour	-------- *dollars/unit* --------		
Used MOBLOW	25	6.67	3.33	2.22
New MOBLOW	28	7.47	3.74	2.49
New heavy-duty MOBLOW	30	8.00	4.00	2.66

sive" equipment. Regardless of the machines that are used, the production rate must exceed 2 acres per day for seedbed mulching, and 6,000 square feet per day for shrub-bed mulching, to keep unit costs competitive with other mulching techniques.

Contractors or landscapers can determine total mulching costs for bidding and other purposes by adding the price of bark mulch to our estimates of application costs (tables 4,5). They also may find our estimates useful for comparing the cost of mulching with bark to the cost of mulching with straw, hay, or wood-cellulose fiber.

SUMMARY AND CONCLUSION

We found that bark blower trucks equipped according to MOBLOW specifications can effectively apply pine and hardwood bark products, screened sawdust, and wood shavings, but cannot handle unprocessed bark residues. Other equipment or methods are required for the application of unprocessed barks for mulch or bedding uses. On-the-job mulching trials in which shredded hardwood bark was used demonstrated MOBLOW's efficiency in mulching seedings on long, steep slopes, and highway plantings of large shrub beds.

We developed mulching production rates and costs for seven equipment/manpower systems employing MOBLOW. Unit costs for mulching jobs at average production rates seemed to fall within the range of costs for other mulching methods.

MOBLOW's performance on mulching jobs and its capability for doing other work makes it a versatile machine. It—or other mobile equipment with high-pressure blowers and rotary airlocks—can be used by seeding and mulching contractors, landscapers, employees of highway and park departments, and others who apply large volumes of mulch and bedding materials.

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APPENDIX

MOBILE BARK BLOWER SPECIFICATIONS

Truck chassis and engine:

Year and make: 1959 Reo.
Gross vehicle weight rating: 48,000 pounds
Tandem rear axle: 32M Eaton
Front axle: Timken FD901
Engine: Reo O.H. 200 "Gold Comet"
Fuel: Gasoline
Main transmission: Clark 290V
Auxiliary transmission: Spicer 6041
Tires: 9.00 x 20
Brakes: Air
P.T.O's: Two power take-offs from engine; one powers a hydraulic pump, the other a high-pressure rotary blower.

Hydraulic system: Oil reservoir, hydraulic pump, two orbital motors, telescoping and single-action cylinders, and two-way control valves.

Blower unit: 6-71 GMC high-pressure rotary blower.

Airlock unit: 16 x 20 rotary feeder driven by hydraulic orbital motor.

Blower hose: Ten 12-foot lengths of 4-inch flexible metal hose fitted with quick couplers.

Truck box: Capacity 30 cubic yards; heavy-duty steel construction; moveable front bulkhead powered by telescoping hydraulic cylinder with cable return; top-mounted, hydraulically-operated rear door.

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- Warren, Pennsylvania.

Sarles, Raymond L., and David M. Emanuel.
1977. **The mobile bark blower: An evaluation of performance and costs.** Northeast. For. Exp. Stn., Upper Darby, Pa.
9 p., illus. (USDA For. Serv. Res. Pap. NE-368)

A custom-built bark blower truck (MOBLOW) developed in Oregon was tested for its effectiveness in applying bark mulches, sawdust, and shavings in the eastern United States. Tests determined the bark blower's performance and cost in mulching grass-legume seedings and shrub beds with 10 bark products or wood residues. Bark blower trucks built to MOBLOW specifications can effectively apply pine and hardwood bark products, sawdust, and wood shavings, but cannot handle unprocessed bark residues. Blower trucks can be used to blow shredded bark, sawdust, and shavings into barns, cattle sheds, poultry houses, show rings, and corrals, and to deliver hogged fuel.

839.8:892.4:(017.4)--(74)/(77)

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ABSTRACT

Labor turnover in hardwood sawmills of the Appalachian Region was studied by using data collected during interviews with 68 mill managers. Job-quitting was highest among young unskilled workers who had less than 6 months of service with their employers. Half of the mills surveyed had annual quit rates of more than 100 percent. Variation among mills was associated with the age of mill employees, wages and the number of paid holidays received by the workers, and the general wage level and unemployment rate in the local labor market. Lumber output per man-hour varied inversely with quit rates. In managing turnover, employers are encouraged to balance the cost of higher wages and fringe benefits with the benefits of greater labor stability.

THE WORKER WHO QUITS

IT HAPPENS almost every day—an employee leaves, and another is hired to replace him. We call this "employee turnover". What motivates workers to quit jobs has often puzzled employers. Was it something the foreman said?; did another firm offer a higher wage?; or was there some aspect of the job itself that was troubling the employee? Supervisors are often the last to find out, and then usually after it is too late to change the employee's decision to leave.

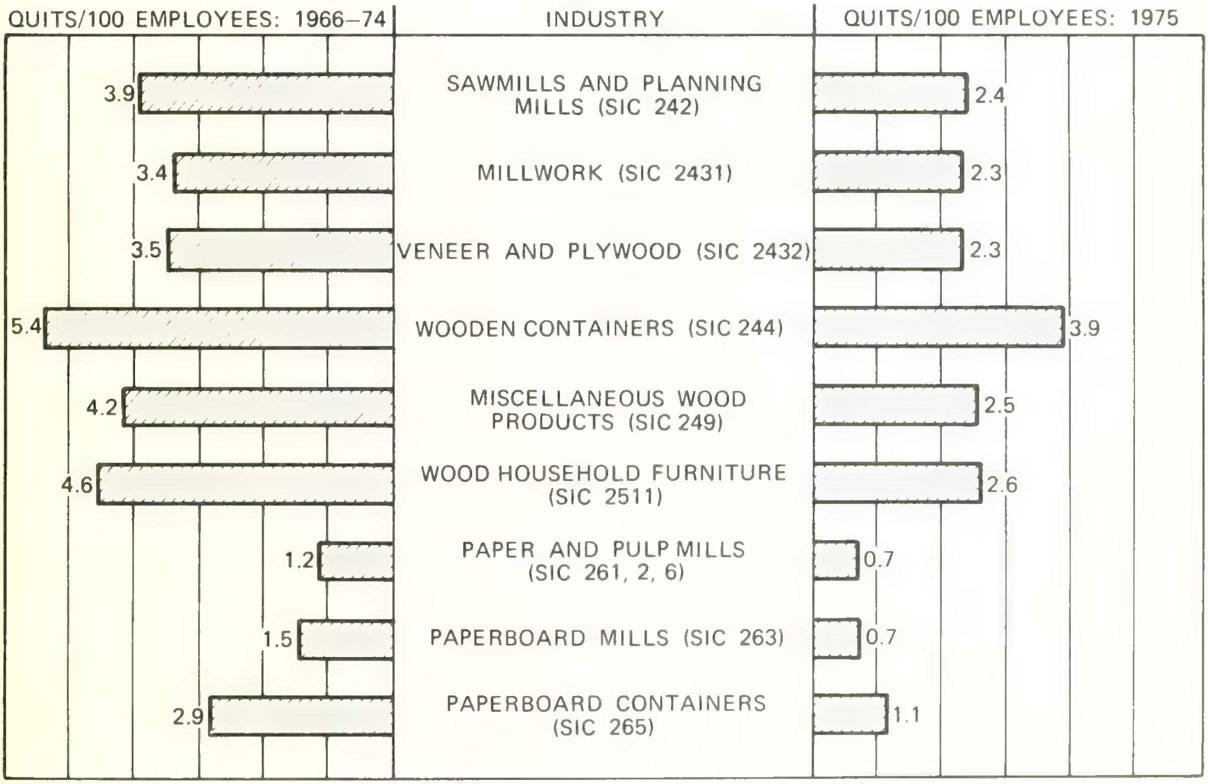
As a group, workers employed in the lumber and wood-products industry quit their jobs twice as often as workers employed in other durable-goods industries. Job quitting is most prevalent among workers producing wooden containers, household furniture, lumber, and miscellaneous wood products (fig. 1). The tendency to quit is strongest during expansions in economic activity and weakest during recessions (fig. 2).

The casual attachment between workers and their employers is also reflected in the high proportion of workers with short job tenure. A survey in January 1973 showed that nearly one of every four workers employed in the lumber and wood-products industry had worked only 6 months or less for his employer *(Hayghe 1975)*.

Why workers quit, and what effect this has on operating efficiency, is of particular concern to employers in the lumber and wood-products industry. This concern was intensified by labor shortages that occurred in the late 1960s and early 1970s. Employers found that they had to hire two and even three times more new employees than usual to maintain full work crews. In some firms, plans to operate a second shift or to open a new plant were delayed by this even though the market for wood products justified an expansion in production activities.

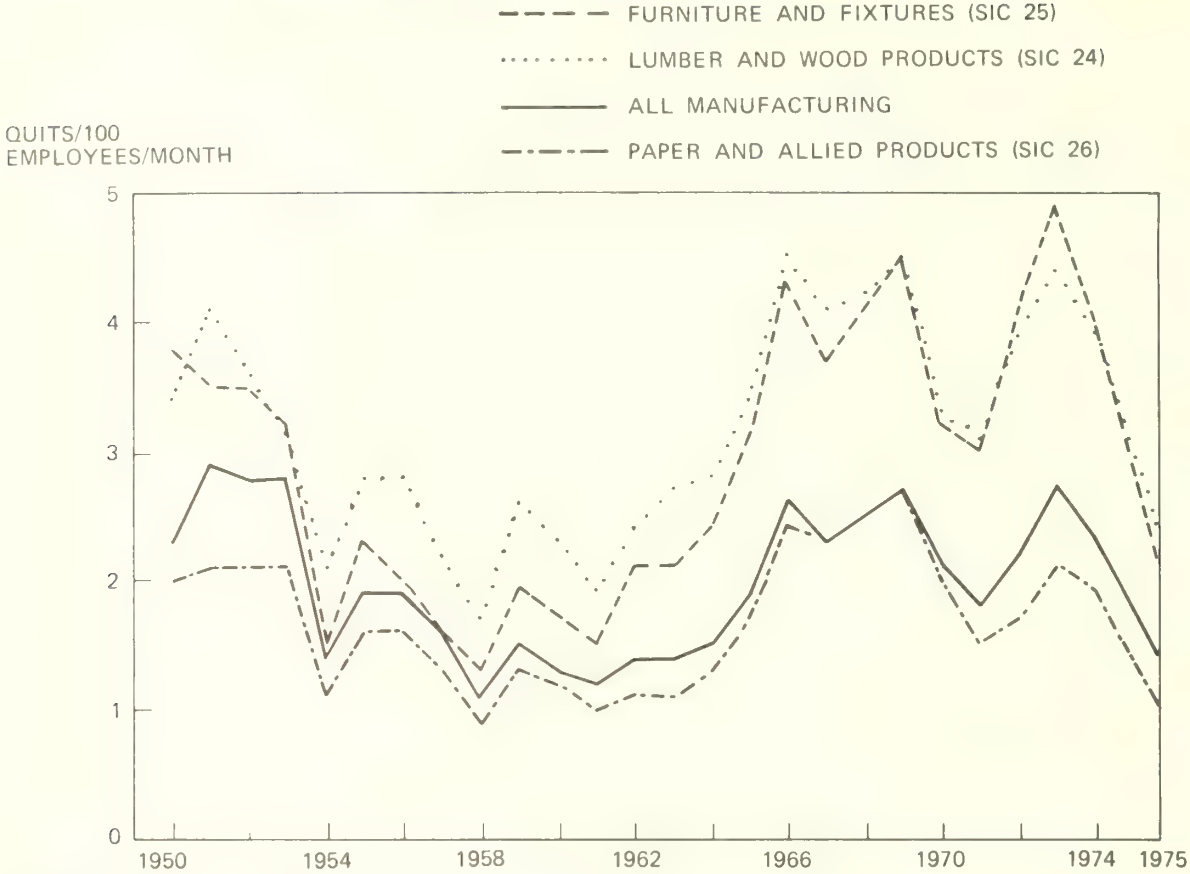
Whenever an employee quits, the investment

Figure 1.—Average monthly quit rates for selected wood-products industries, 1966-74 and 1975.



Source: Employment and Earnings (1967-76), Table D-2.

Figure 2.—Quit rates of major industry groups, 1950-75.



Source: U.S. Department of Labor, Handbook of labor statistics (1975).

that was made to hire and train him is lost to his employer. Because most workers leave without warning, replacements may not be available when needed; and this results in bottlenecks along the production line and less effective planning, scheduling, and organizing. Even after vacancies are filled, new employees—while learning their jobs—are less efficient than the workers they replaced. Their inexperience can lead to increased machinery maintenance, an unnecessary waste of raw materials, a decline in the quality of workmanship, and poorer customer service. All these factors tend to push up costs and lower productivity.

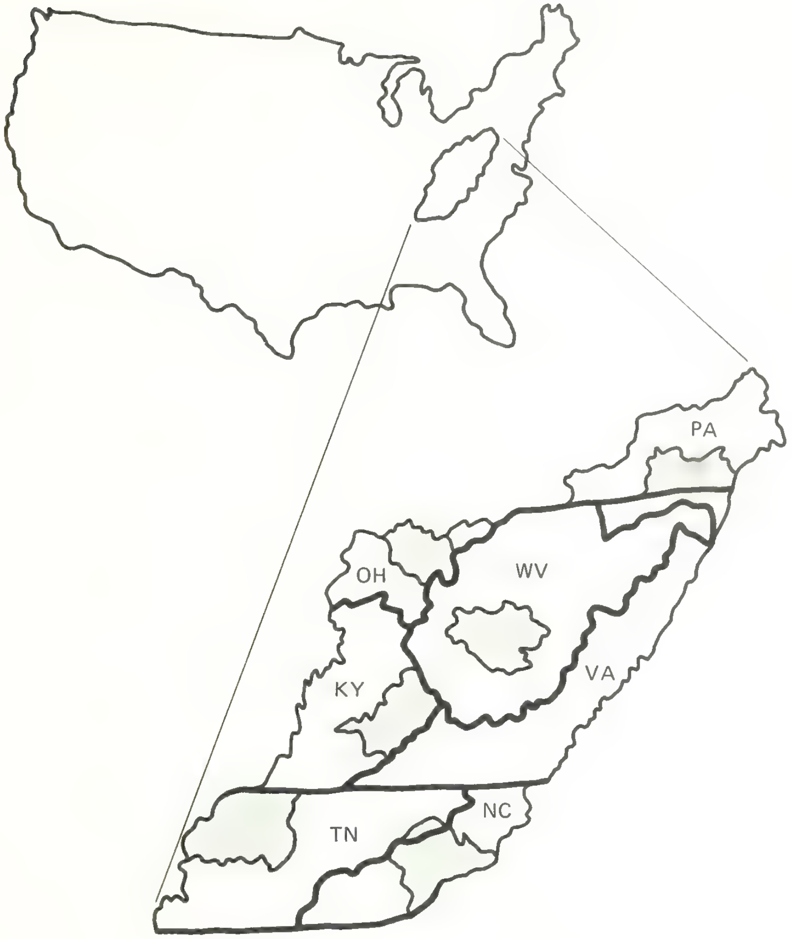
This study was made to find out more about job-quitting in the lumber and wood-products industry. The scope of the study was limited to hardwood sawmills in the Appalachian Region. Answers were sought to three basic questions: (1) What is the quit rate for sawmills in this region? (2) Why do sawmill workers quit their jobs? (3) What can mill managers do to reduce employee turnover?

METHODS AND PROCEDURES

The data used to answer these questions were obtained during personal interviews with managers in a sample of Appalachian hardwood sawmills. To obtain this sample, the Appalachian Region was divided into 32 sample clusters. The clusters were roughly equal in area, and each consisted of two or more counties. Six of the clusters were selected randomly—three from the northern half of the region and three from the southern (fig. 3).

Within these six clusters, hardwood sawmills that produced 1 million board feet or more of lumber in 1972 and employed five or more non-

Figure 3.—The Appalachian study region. Shading indicates locations of sample areas.



supervisory production workers were included in the sample. Sixty-eight of the 70 sawmills that satisfied these requirements participated in the field interviews. However, the responses varied because some mill supervisors did not feel qualified to answer certain questions, and records were not available at all mills.

A structured questionnaire was used to record the interviews. Tabulations on wages and several other variables were made from company payroll, personnel, and production records. Local labor-market data were obtained from state employment security agencies and the COUNTY AND CITY DATA BOOK *(U.S. Census Bureau 1973b).*

The subjects of the study were full-time hourly production and maintenance workers holding nonsupervisory positions in the mill and lumberyard. This group excludes loggers, clerical employees, sales personnel, truckdrivers, salaried workers, and students employed during the summer or after school hours.

An annual quit rate was calculated for each mill by dividing the total number of quits occurring during 1972 by the mill's average quarterly employment and multiplying by 100 to obtain a percentage. These rates are not comparable to those published by the Bureau of Labor Statistics *(1975)* because they are developed for a narrowly defined group of sawmill workers and are based on annual rather than monthly data. The number of quits was found by determining the total number of employee separations using the mill's payroll records and subtracting from this all layoffs, firings, and miscellaneous separations as reported by the mill supervisor.

GENERAL FINDINGS

Job-quitting was clearly the most important form of labor turnover, accounting for 91 percent of all employee separations. Layoffs and firings accounted for only 6 percent of all separations, while the remaining 3 percent were the result of death, retirement, poor health, and other miscellaneous reasons.

The annual quit rate for the sample mills averaged 118.6 percent and ranged from zero to as high as 571 percent (table 1). When these data were weighted by average employment, the mean was 112.4 percent, indicating very little variation by mill size. Quit rates for mills in the northern half of the study region were not significantly different from those in the southern half.

The number of workers who quit in the typical mill was about equal to the mill's average employment. Most of these workers held unskilled jobs such as machine offbearer, chipper operator, and lumber handler. Because of the quick entry and exit of new workers, it was not uncommon to find four or five different individuals employed in the same job during a year. Only 8 percent of all quits involved workers who held skilled jobs: sawyers, sawfilers, edgermen, trimmermen, forklift operators, lumber graders, log scalers, and millwrights.

Despite the small proportion of skilled workers who quit, turnover was still quite serious. Eighteen percent of the mills had one or more sawyers quit, and 34 percent had at least one edgerman quit during the year (fig. 4).

Labor turnover is more detrimental to a business if it occurs among employees who have had a long period of service with their employer. Such workers are especially valuable because they are familiar with company policies and experienced in the operation and maintenance of company equipment. In the sample, workers with at least 6 months of service comprised three-fourths of all employees, but accounted for only slightly more than one-fourth of all those who quit.

WHY WORKERS QUIT

Two approaches were used to determine why sawmill workers quit their jobs. The first approach was to question mill supervisors. It was felt that they would be able to provide insight into the causes of turnover that could not be obtained through statistical analyses. A possible drawback of this approach is that mill supervisors may not be fully aware of the reasons why their employees quit because many who do so leave without prior warning.

The second approach was to develop a series of hypotheses about factors believed to influence quit rates in sawmills. These hypotheses were tested in a regression model that predicted quit rates in the sample mills.

MANAGEMENT OPINION SURVEY

Mill managers were asked to give the major reasons why their employees quit. The most frequently given reasons were linked to the economic motives of the employees (table 2). Better jobs and higher wages accounted for 40 percent of the response, and from management's viewpoint, these appeared to be the primary reasons why workers quit.

Some managers strongly believed that turnover, absenteeism, and other labor-related problems were caused by government income-transfer programs such as food stamps, aid to

Table 1.—Labor turnover rates in the Appalachian lumber industry, 1972

Turnover rates[1]	Mean	Median	Minimum	Maximum
Quit rate	118.6	101.5	0.0	571.0
Discharge rate	9.1	0.0	0.0	133.0
Layoff rate	2.0	0.0	0.0	100.0
Miscellaneous separation rate	4.0	2.5	0.0	65.0
All separations	133.7	110.0	5.0	571.0

[1] Rates indicate the number of turnover actions per 100 employees per year. Data are based on 62 sawmills.

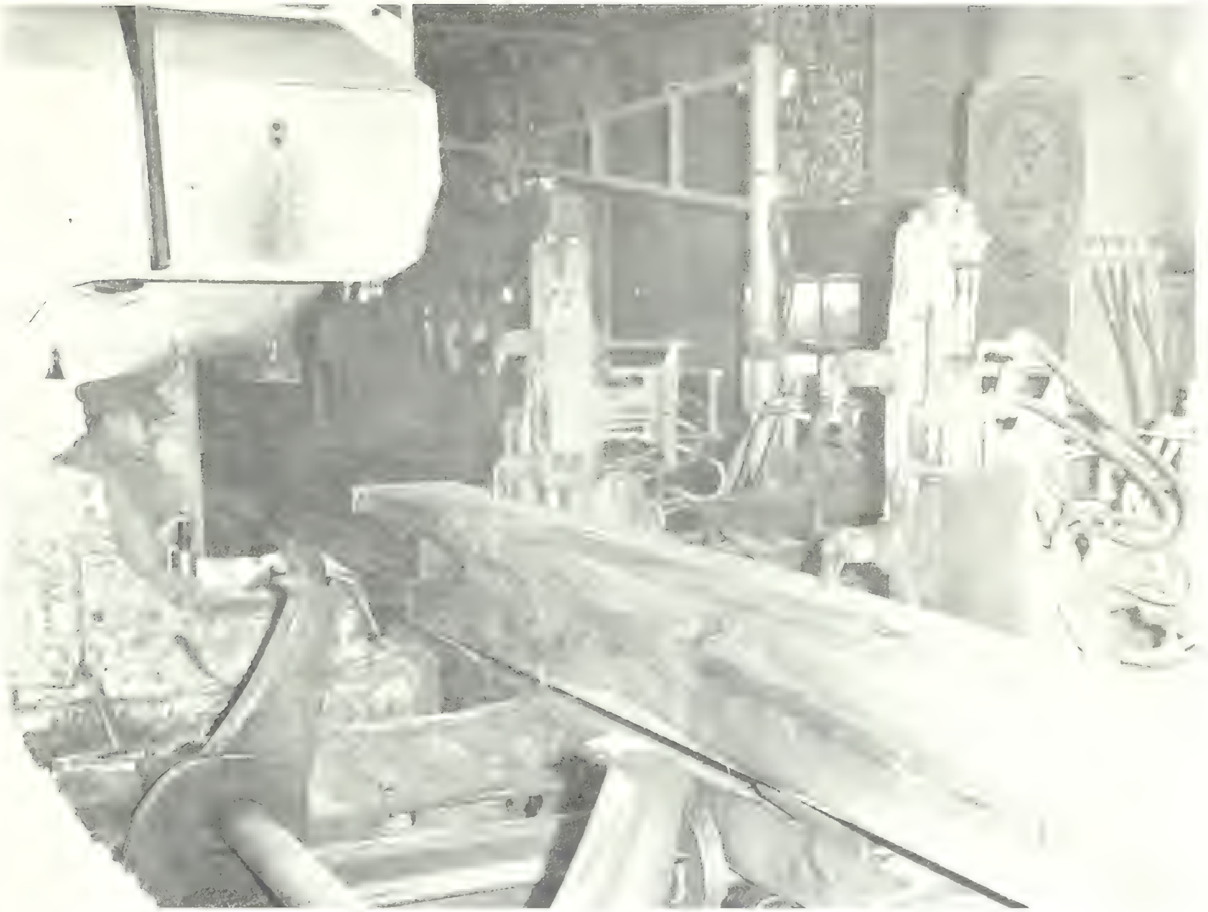


Figure 4.—Sawyers are key production workers who are hard to replace. Their loss can disrupt and even halt lumber production.

families with dependent children, and unemployment insurance. Many sawmill workers qualify to participate in one or more of these programs. In 1969, 12.9 percent of the male family heads employed in the industry had a total family income that was below the federal poverty level *(U.S. Census Bureau 1973a.)*

A congressional study of these programs supports management's view that they are a contributing factor to the high rate of turnover *(Lerman 1972)*. The study found that some programs are structured in such a way that they actually inhibit stable employment and encourage workers to concentrate their earnings over short periods.

Another aspect of these programs is that, by creating an artificial income floor, they substantially reduce the risk involved in changing jobs. This is especially true for low-wage earners whose incomes are only slightly above the benefit levels established by the programs.

The strenuous nature of sawmill work was also mentioned as a reason for workers' quitting. Mill managers felt that workers wanted easier, less physically-demanding work than was available in the sawmill industry. Other reasons given for quitting were laziness, employee-supervisor disagreements over pay and job assignments, working conditions, transportation problems, and alcoholism.

REGRESSION ANALYSIS

Explanatory Variables

In previous studies, a large number of factors have been identified that seem to be associated with variation in the quit rate. Based on a review of these studies and discussions with in-

Table 2.—Major reasons why employees quit, as reported by mill supervisors[1]

Reason for quitting	Number of mentions	Percent of total
Better job	24	22.2
Higher wages	19	17.6
Welfare programs	16	14.8
Laziness	16	14.8
Work too strenuous	10	9.3
Conflict with supervisor	7	6.5
Working conditions	2	1.8
Other reasons[2]	14	13.0
Total	108	100.0

[1] Sixty-five supervisors responded to the question. Some reported more than one reason why their employees quit.

[2] Includes reasons related to transportation, job safety, alcoholism, and family circumstances.

dividuals familiar with the sawmill industry, 15 variables were identified as possible predictors of the quit rate (table 3). These variables relate to employee remuneration, the work environment in sawmills, the characteristics of the workers, and the conditions within local labor markets *(Wolf 1975)*.

Wages are commonly felt to be one of the most important factors affecting quit rates. Interindustry studies show that low-wage industries have higher quit rates than high-wage industries *(Armknecht and Early 1972, Pencavel 1970, Stoikov and Raimon 1968)*. This inverse relationship was also expected to hold true for sawmills within the lumber industry. Wage supplements such as paid vacations and hospitalization and life insurance are likely to influence quit rates in a similar manner.

The relationship between quit rates and mill size is not very clear. It could be argued that small mills would have lower quit rates than large ones because, the smaller the work group, the less conflict there is likely to be between the individual and the organization. Nepotism is also likely to be more prevalent in small mills. Conversely, small mills may have higher quit rates because they provide fewer opportunities for advancement and are generally less capable of handling personnel functions such as employee selection, training, and counseling.

Working conditions are determined by such things as the adequacy of ventilation, lighting, and heating; the availability of washroom and eating facilities; and the amount of manual loading and stacking. These conditions, plus the danger associated with the work and the steadiness of employment, seem likely to contribute to the variation in quit rates.

A worker's impluse to quit may be influenced heavily by the actions of his supervisor. The Leadership Opinion Questionnaire devised by Fleishman *(1960)* contains 40 multiple-choice questions that indicate how supervisors feel they should behave in their leadership roles. Scores are developed on two independent dimensions of supervision that are labeled *consideration* and *structure*. Quit rates were expected to be lowest in sawmills where supervisors scored high in consideration and low in structure.

A positive relationship was expected to exist between the proportion of workers less than 30 years old and the quit rate. This would be consistent with other studies in which it has been found that the tendency to quit decreases with age.

High school graduates were believed to change employers more often than nongraduates because they can satisfy the minimum education requirements of a larger number of employers, and they tend to be better informed about job opportunities. They also have proportionately less training that is specific to the sawmill industry and to individual employers.

Unions tend to inhibit job-quitting by emphasizing internal promotions and by fostering seniority protection, pension rights, and other benefits that accrue with length of service. They are partly responsible for grievance procedures that minimize the need to change employers to obtain relief from real or imagined injustices.

The local unemployment rate and the average manufacturing wage were thought to reflect the opportunities and financial incentives that might impel dissatisfied sawmill workers to change employers. Mills located in labor markets with low unemployment and high manufacturing wages were expected to have higher-than-average quit rates.

Sawmill workers living in urban labor markets were expected to have higher quit rates than those living in rural ones. This is because the cost of job search is lower in urban areas as a result of more employment alternatives, greater exposure to help-wanted advertising,

Table 3.—Description, expected sign, and correlation coefficients of independent variables used to predict the quit rate

Description of variable	Symbol used in analysis	Expected effect of an increase in variable on the quit rate	Simple correlation with quit rate	Significance level	Sample size
Employee remuneration:					
1. Average wage for production workers	AW	Negative	-0.189	0.071	62
2. Number of paid holidays and vacation days provided to employees with 1 year of service	H	Negative	- .228	.037	62
3. Employer-paid hospitalization and life insurance (1=paid; 0=not paid)	I	Negative	- .271	.016	62
Work environment:					
4. Average employment	EMP	Uncertain	- .011	.467	62
5. Operating days per year	DAY	Negative	.139	.140	62
6. Working conditions score	WC	Negative	- .153	.119	61
7. Accident frequency rate	AFR	Positive	.175	.089	61
8. Leadership style (consideration score)	LCS	Negative	- .059	.345	48
9. Leadership style (structure score)	LSS	Positive	.043	.385	48
Employee characteristics:					
10. Proportion of workers less than 30 years of age	AGE	Positive	.546	.001	62
11. Proportion of workers completing high school	ED	Positive	- .287	.020	52
12. Union membership (1=union; 0=nonunion)	UN	Negative	- .118	.180	62
Local labor market:					
13. County unemployment rate	UEM	Negative	- .216	.046	62
14. County manufacturing wage	MW	Positive	.404	.001	62
15. Proportion of county residents living in urban areas	URB	Positive	.383	.001	62

and better access to public and private employment agencies. A change of employers in urban areas is also less likely to involve the monetary and psychological costs of moving to a new community.

Results

Multiple-regression analysis was used to test these hypotheses and to determine how well the explanatory variables predicted the quit rate. After several exploratory regression equations were examined, it became apparent that some variables contributed little, if anything, to the prediction of quit rates. For this reason, average employment, number of operating days, and leadership style were dropped from the analysis. The proportion of workers who had graduated from high school was tested in regression equations separate from those presented in order to conserve degrees of freedom.

The remaining variables were included in the following regression equation.

$$\begin{aligned}\hat{Q}_i = {} & 200.94 - \underset{(48.76)^{*}}{93.75\mathrm{AW}} - \underset{(3.32)^{**}}{8.10\mathrm{H}} - \underset{(27.01)}{0.04\mathrm{I}} \\ & + \underset{(5.98)}{3.79\mathrm{WC}} + \underset{(0.64)}{0.49\mathrm{AFR}} + \underset{(0.53)^{**}}{2.38\mathrm{AGE}} - \underset{(48.53)}{9.92\mathrm{UN}} \\ & - \underset{(3.00)^{*}}{6.45\mathrm{UEM}} + \underset{(0.80)}{0.11\mathrm{URB}} + \underset{(18.83)}{30.45\mathrm{MW}}\end{aligned}$$

$$N = 60 \qquad \bar{Q} = 120.8$$
$$R^2 = 0.56 \qquad \mathrm{SEE} = 77.6$$

Here $\hat{Q}_i$ denotes the estimated annual quit rate in the i^{th} sawmill, and the symbols representing the explanatory variables are defined in table 3. Standard errors are shown in parentheses below the partial regression coefficients above. The 0.01 and 0.05 significance levels are indicated by ** and * respectively.

In this equation there were four statistically significant variables—the average wage (AW), the number of paid holidays and vacation days (H), the proportion of employees under 30 years old (AGE), and the county unemployment rate (UEM). An examination of the remaining variables showed that the county manufacturing wage (MW) and the proportion of the county's population that was urban (URB) had a relatively high correlation (r = 0.634), which could explain why neither was significant.

A final and "best" regression equation with only five explanatory variables was estimated as follows:

$$\hat{Q}_i = \underset{}{208.56} - \underset{(41.24)^{*}}{89.63AW} - \underset{(2.32)^{**}}{7.28H} + \underset{(0.45)^{**}}{2.29AGE}$$

$$= \underset{(2.68)^{**}}{6.70UEM} + \underset{(12.18)^{**}}{33.05MW}$$

$$N = 62 \qquad \bar{Q} = 118.6$$
$$R^2 = 0.55 \qquad SEE = 74.5$$

The five independent variables explained 55 percent of the intermill variation in quit rates or about the same as in the previous regression equation.

In theory, the relationship between many of the independent variables and the quit rate is nonlinear. For instance, successively higher wages rates and greater vacation time could be expected to lead to smaller incremental declines in the quit rate. Several transformations—log-log, semilog, and reciprocal—were used to modify the data so they would satisfy these theoretical considerations. However, all models using transformed data explained about the same or slightly less variation than the ones presented.

To summarize, the regression analysis showed that five variables—the age of the work force, the average wage, the number of holidays and vacation days, and the manufacturing wage and unemployment rate in the local labor market—were statistically significant predictors of the quit rate. A comparison of the normalized regression coefficients of these variables showed that the age of the work force was clearly the most important predictor. Holidays and vacation days was second, and the average wage was third.

Discussion

The relationship between age and labor mobility has been well documented in other studies. Thus it is not surprising to find that the age distribution of the work force is one of the key determinants of job-quitting in Appalachian sawmills. In the sample mills, 39 percent of the workers were under 30 years of age. However, this age group accounted for 70 percent of the workers who quit.

Human capital theory offers an explanation of why young workers change jobs more often than older workers *(Becker 1964)*. In this theory, changing employers is viewed as an investment that is associated with certain costs (job search, moving expenses) and returns (higher wages) that are discounted over an individuals's expected span of employment. For similar investments, the shorter the expected span of employment, the lower the rate of return to the individual. Consequently, a young person is likely to have more to gain from changing employers than an older person whose working life is about to end. Institutional factors such as seniority rights, restrictive pension plans, wage increases based on length of service, and age discrimination in hiring also help to explain why the tendency to change jobs declines with age.

The importance of wages in the regression analysis supports the observations by mill managers that many workers had quit to take higher-paying jobs in other firms. During 1972, the average wage paid by the sample firms was $2.17 per hour for nonsupervisory production and maintenance workers.

The wage rates of other firms in the labor market are as important as those in the sawmill industry in determining the quit rate. An employer may be paying high wages by lumber-industry standards only to find that his quit rate is also high because he is located in a high-wage labor market.

The importance of employer-paid holidays and vacation time as a predictor of the quit rate points out that workers are not only aware of, but also respond to differences in the level of nonwage compensation. Fifty-six percent of the sample firms did not provide any paid holidays, and 54 percent did not provide any paid vacations to employees with 1 year of service. The average number of paid holidays and vacation days given annually by the sample firms was 4.3. Employers in the sawmill industry seem to have underestimated the significance of such fringe benefits as a means of attracting and retaining qualified personnel.

The country unemployment rate was the other local labor-market variable that influenced the quit rate. A low unemployment rate denotes a tight labor market, where the opportunity to obtain another job is very good;

whereas a high unemployment rate indicates situations in which workers stay with their employers even though certain aspects of their jobs (wages, supervision) may not be agreeable. They stay rather than quit and take the risk of not being able to find other work.

Mill size, as measured by average employment, was not found to be related to job-quitting. Therefore, it appears that large mills in the lumber industry are affected by employee turnover to the same degree as small ones.

There are several possible reasons why the other variables previously thought to influence turnover did not prove useful in predicting the quit rate. For example, because working conditions and supervisory style are very difficult to quantify, there may have been errors in measurement that affected the results. Other means of quantifying these variables should be devised and tested to confirm or reject the findings of this study.

The two binary variables (union membership and employer-paid insurance) might have shown a stronger relationship with the quit rate if the scale of measurement had reflected more of the qualitative aspects of the variables. The number of days that mills operated did not influence quit rates because nearly all mills in the sample operated 250 or more days per year.

TURNOVER AND PRODUCTIVITY

Many, but not all, of the benefits attributable to labor stability appear as improvements in productivity. To measure these benefits, a production function was estimated that included the annual quit rate as an independent variable. Annual production measured in thousands of board feet was estimated as a function of man-hours worked per year, average number of kilowatt hours of electrical energy used per 8-hour shift, and the annual quit rate. The electrical energy consumed per shift was included as a proxy for capital investment.

Data for estimating this equation were collected at only 15 sample mills. Many mills either did not keep production records or had a product mix that included mine timbers, railroad ties, and wood products other than hardwood lumber. Despite the small sample, the analysis was continued to gain further insight into the relationship between labor turnover and productivity.

A two-tailed t-test showed that there was no significant difference in the mean employment and quit rate of the mills used in estimating the production function and the others included as part of the larger industry sample.

The regression coefficient for the quit rate in the log-log form of the production function had a negative sign, indicating that, as job-quitting increased, production declined. The coefficient, statistically significant at the 0.05 level, indicated that a 10-percent decrease in the annual quit rate would be associated with a 6/10-percent increase in annual production.

This finding becomes more meaningful when expressed in units of production. To illustrate: average annual production in the sample mills was 4.289 million board feet, and the average annual quit rate was 118.6. If the number of quits were reduced to 30 per 100 employees, annual output in the average firm would be expected to increase by 4.7 percent or about 202 thousand board feet.

This additional output would have a market value of about $30,000. After deducting the cost of raw material, the financial gain from reducing the quit rate would be about $17,000.

This attempt to quantify the effect of job-quitting on sawmill production was mainly exploratory. It nevertheless provided evidence that an unstable labor force will result in lower lumber production. This finding seems reasonable; however, there may be some disagreement over the exact magnitude of the effect. A stronger relationship between production and quit rates would be expected where a higher proportion of quits involves skilled workers.

SUMMARY AND CONCLUSIONS

The Appalachian lumber industry was found to have very high quit rates. In the typical hardwood sawmill, the number of employees who quit was about equal annually to the mill's average employment. The majority of those who quit their jobs were under 30 years of age, did unskilled work, and had less than 6 months of service with their employers.

The study showed that mill managers in the Appalachian sawmill industry could exercise at least three options to reduce voluntary turnover. They could (1) increase wages, (2) grant additional paid holidays and vacation time, or (3) increase the proportion of older employees through changes in recruiting and hiring practices. Local unemployment rates and manufacturing wage levels were also found to influence quit rates; however, mill managers have no control over these variables.

In deciding which option or combination of options to follow, the mill manager must answer two questions. First, what benefits can the firm expect to achieve by lowering the quit rate? Second, will these benefits be greater than the higher payroll and other expenses necessary to achieve them?

It should be recognized that an increase in employee compensation will result in greater labor stability. This stability will lead to additional lumber production and lower training and hiring costs. An employer's objective should be to balance the cost of higher employee compensation with the benefits of greater labor stability. Because these costs and benefits will not be the same throughout the industry, each employer must evaluate his own situation to decide what course of action is best for his firm.

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Quality Index Tables for Some Eastern Hardwood Species Based on Lumber Prices from 1970 to 1974

by Joseph J. Mendel and Margaret K. Peirsol

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Quality Index Tables for Some Eastern Hardwood Species Based on Lumber Prices from 1970 to 1974

ABSTRACT

Revised quality index (QI) tables for white ash, beech, black cherry, birch, hard maple, soft maple, red oak, white oak, and yellow-poplar are based on 1970-74 lumber prices for the Appalachian and northeastern marketing areas. Changes in QI since 1964-68 were greatest for white oak; there also were significant changes in QI for red oak, white ash, and yellow-poplar.

Keywords: hardwoods, value, sawtimber, prices.

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- Warren, Pennsylvania.

AN UPDATING OF QI

IN THIS PAPER we have revised quality index (QI) tables that were reported in a previous study *(Mendel and Smith 1970).* The QI's in that study were based on lumber prices from 1964 to 1968; the updated quality indexes are based on lumber prices from 1970 to 1974. The QI changes periodically because of changes in price ratios for different grades of lumber. These changing ratios affect the value of the lumber that can be sawed from a log.

WHAT IS QI?

The QI is an index number similar to the U.S. Department of Commerce Consumer Price Index. All index numbers must have a base and the base for QI is the price of 4/4 No. 1 Common lumber; later we will use this base in calculating log value. The QI expresses the relative value of the lumber in a log based on the amount of different grades of 4/4 (per thousand board feet) lumber that can be sawed from a log. The formula for QI is:

$$\begin{aligned} QI = {} & (\%\ \text{FAS} \times PR_{\text{FAS}}) + (\%\ \text{SEL} \times PR_{\text{SEL}}) + \\ & (\%\ \text{No. 1C} \times PR_{\text{No. 1C}}) + \dots\dots\dots \\ & (\%\ \text{No. 3B} \times PR_{\text{No. 3B}}) \end{aligned}$$

where % FAS and % SEL are the percentages of the total volume of lumber that can be sawed from logs that will grade First and Second and Select, respectively. PR_{FAS} is the price relative for

$$\text{FAS lumber} \left(\frac{\text{Price 4/4 FAS lumber/M BM}}{\text{Price 4/4 No. 1 Common/MBM}}\right)$$

For this study, price relatives are 5-year average price relatives for different grades of lumber.

CALCULATING THE QI

Two sets of data are needed to calculate the QI: (1) lumber grade yields by diameter, log grade, and species, and (2) lumber prices for 4/4 lumber, by grade, to calculate the price relatives.

For our calculations we obtained lumber grade yields from a study by Vaughn et al *(1966).*

The lumber price relatives were developed from prices reported from 1970 to 1974 in the *Hardwood Market Report* and in *The Commercial Bulletin.*

The PR's for No. 1 Common are always 1.00 because that grade is the base for the index (table 1A). The PR's for FAS and SEL grades are more than 1.00, and the PR's for No. 2 Common, No. 3A Common, and No. 3B Common are all less than 1.00. Prices for FAS and SEL lumber are higher than that for No. 1C, while the prices for No. 2C, No. 3A, and No. 3B lumber are lower than that for No. 1C. Table 1B shows the price relatives for 1970-74 compared to those for 1964-68.

To explain how the QI is calculated, let's use a 16-foot-long Grade 1 white ash log that is 16 inches in diameter inside bark (dib). Lumber grade yields are: 41.4 percent FAS, 11.0 percent SEL, 26.5 percent No. 1C, 12.3 percent No. 2C, 4.4 percent No. 3A, and 4.4 percent No. 3B. If we use the price relatives from table 1, our formula is:

$$\begin{aligned} QI = {} & (.414 \times 1.51) + (.110 \times 1.47) + (.265 \times 1.00) \\ & + (.123 \times .50) + (.044 \times .42) + (.044 \times .37) \end{aligned}$$

$$QI = 1.149 \text{ or } 1.15.$$

Table 1A.—*Lumber price relatives by grade and species, and market* (Basis: 4/4 No. 1 COMMON, the reference grade)

Species and market	Lumber grade							
	FAS	SEL	SAPS	No. 1C	No. 2C No. 2A	No. 2B	No. 3A	No. 3B
Market I [a]								
White ash	1.51	1.47	—	1.00	.50	—	.42	.37
Beech	1.22	1.15	—	1.00	.63	—	.50	.44
Black cherry	1.44	1.39	—	1.00	.51	—	.43	.41
Hard maple	1.48	1.43	—	1.00	.51	—	.46	.31
Soft maple	1.27	1.23	—	1.00	.49	—	.45	.31
Red oak	1.53	1.48	—	1.00	.57	—	.52	.33
White oak	1.52	1.46	—	1.00	.59	—	.53	.35
Yellow-poplar	1.33	1.28	1.23	1.00	.67	.47	.23	.23
Market II [b]								
White ash	1.51	1.46	—	1.00	.48	—	.38	.34
Beech	1.21	1.15	—	1.00	.52	—	.41	.37
Black cherry	1.43	1.39	—	1.00	.46	—	.26	.24
Hard maple	1.47	1.43	—	1.00	.55	—	.40	.29
Red oak	1.50	1.45	—	1.00	.58	—	.51	.33
White oak	1.49	1.43	—	1.00	.53	—	.46	.30
Yellow-poplar	1.32	1.28	1.22	1.00	.64	.44	.22	.22
Market III [c]								
White ash	1.46	1.40	—	1.00	.46	—	.36	.32
Beech	1.24	1.11	—	1.00	.53	—	.41	.37
Birch	1.72	1.62	—	1.00	.63	—	.47	.29
Hard maple	1.52	1.42	—	1.00	.64	—	.51	.40
Soft maple	1.36	1.23	—	1.00	.54	—	.39	.30
Oak	1.44	1.34	—	1.00	.61	—	.55	.40

[a] Based on 1970-74 lumber prices for Appalachian hardwoods, from the *Hardwood Market Report*, f.o.b. mills, Johnson City Tennessee, area.

[b] Based on 1970-74 prices for Appalachian hardwoods, from *The Commercial Bulletin*, for rough and air-dried lumber, f.o.b. mill, wholesale commission included.

[c] Based on 1970-74 prices for northeastern hardwoods, from *The Commercial Bulletin*, for rough and air-dried lumber, f.o.b. mill, wholesale commission included.

The QI that was based on 1964-68 prices for that log grade and size class of white ash was 1.21; therefore the QI has changed by -.06 between the two base periods (table 1C). Now let's see how this change affects the value of the lumber in the log.

DETERMINING LOG VALUE FROM QI

Tables 2 to 22 show the QI's for some of the more important eastern hardwood species; these QI's are based on 1970-74 prices for the Appalachian marketing area as reported by the *Hardwood Market Report* and *The Commercial Bulletin*, and the northeastern marketing area as reported by the *The Commercial Bulletin*. These QI's are simply multiplied by the price of 4/4 No. 1 Common lumber to determine the value of lumber in a log. For example, the *Hardwood Market Report* of January 3, 1976, quoted a price of $290/M bm for 4/4 No. 1 Common white ash. Thus the expected value of lumber (4/4 basis) that can be sawed from our 16-inch Grade 1 white ash log would be calculated:

$$\text{Lumber value} =$$

$$(\text{QI})\,(\text{Price 4/4 No. 1 Common}) \times \frac{\text{Volume of log}}{1000}$$

$$\text{Lumber value} = (1.15)\,(\$290) \times \frac{180}{1000}$$

$$\text{Lumber value} = \$60.03.$$

Table 1B.—*Changes in price relatives between time periods 1964-68 and 1970-74 by markets.*

Species and market	Lumber grade FAS	SEL	SAPS	No. 1C	No. 2C No. 2A	No. 2B	No. 3A	No. 3B
Market I [a]								
White ash	-.12	-.09	—	—	-.03	—	-.02	-.02
Beech	-.03	-.03	—	—	+.09	—	+.08	+.06
Black cherry	-.01	-.01	—	—	+.05	—	+.16	+.16
Hard maple	-.05	-.04	—	—	+.07	—	+.08	+.04
Soft maple	-.01	.00	—	—	+.02	—	+.02	+.01
Red oak	-.12	-.09	—	—	-.07	—	-.04	-.04
White oak	-.30	-.28	—	—	-.07	—	-.05	-.04
Yellow-poplar	-.09	-.08	-.06	—	.00	+.02	.00	.00
Market II [b]								
White ash	-.10	-.06	—	—	-.02	—	-.02	-.01
Beech	-.03	-.03	—	—	-.01	—	-.01	-.01
Black cherry	+.01	+.01	—	—	-.01	—	.00	.00
Hard maple	-.02	-.02	—	—	+.09	—	.00	.00
Red oak	-.13	-.10	—	—	-.04	—	-.03	-.02
White oak	-.31	-.20	—	—	-.01	—	-.10	-.07
Yellow-poplar	-.09	-.06	-.07	—	-.03	-.01	-.01	-.01
Market III [c]								
White ash	-.07	.00	—	—	.00	—	.00	.00
Beech	-.09	-.06	—	—	-.03	—	-.02	-.02
Birch	+.02	+.02	—	—	+.09	—	+.01	+.01
Hard maple	-.05	-.02	—	—	+.04	—	-.01	-.01
Soft maple	+.03	.00	—	—	+.07	—	.00	.00
Oak	-.10	-.02	—	—	-.16	—	-.14	-.10

[a] Based on 1970-74 lumber prices for Appalachian hardwoods, from the *Hardwood Market Report*, f.o.b. mills, Johnson City, Tennessee, area.

[b] Based on 1970-74 prices for Appalachian hardwoods, from *The Commercial Bulletin*, for rough and air-dried lumber, f.o.b. mill, wholesale commission included.

[c] Based on 1970-74 prices for northeastern hardwoods, from *The Commercial Bulletin*, for rough and air-dried lumber, f.o.b. mill, wholesale commission included.

Table 1C.—*Changes in WHITE OAK quality index between 1964-68 and 1970-74*

Log diameter inside bark (inches)	Quality index Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	-.04
9	—	—	-.05
10	—	-.05	-.04
11	—	-.05	-.05
12	—	-.07	-.04
13	-.11	-.06	-.04
14	-.12	-.06	-.05
15	-.12	-.06	-.04
16	-.13	-.06	-.05
17	-.14	-.07	-.05
18	-.15	-.06	-.04
19	-.15	-.07	-.05
20	-.15	-.06	-.04
21	-.16	-.07	-.05
22	-.16	-.07	-.05
23	-.17	-.07	-.05
24	-.17	-.08	-.06
25	-.18	-.08	-.08

CHANGES IN QI SINCE 1964-68

Changes in QI's since 1964-68 were greatest for white oak (table 1C). There also were significant changes in QI for red oak, white ash, and yellow-poplar. These changes are the result of fluctuating supply of and demand for the different grades and species of lumber, and consequent changes in lumber prices. When demand for the higher grades of lumber is great and the supply is low, prices for higher grades increase. During periods of high lumber prices, industries often use a greater proportion of lower grade lumber: this tends to raise prices for lower lumber grades and to lower prices for higher quality lumber grades. Therefore price relatives must be updated frequently to maintain accurate QI's.

For the white oak species we found changes of -.30 and -.28 in the price relatives for the FAS and SEL grades, respectively. The greatest changes in QI for white oak logs were in Grade No. 1C and in the larger diameter classes because these logs yield the greatest percentage of FAS and SEL lumber.

Each change of 0.10 in QI represents a change in the value of a log equal to 1/10 of the price of 4/4 No. 1 Common lumber multiplied by the amount of lumber (of all grades) in the log divided by 1,000. For example, let's assume that the QI changed by 0.1 between the two base periods but that the price of 4/4 No. 1 Common remains unchanged at $220 per M bm, and that the volume is 1,000 board feet: the change in value would be $22.

$$\text{Change} = 1/10 \times (\text{Price No. 1C}) \times \frac{\text{Vol.}}{1000}$$

$$= 1/10 \times \$220 \times \frac{1000}{1000}$$

$$= \$22.$$

To provide a more general summary of changes in QI we classified logs into three groups on the basis of diameter class and log grade (LG):

Large — 24 inches in dib (23 inches in dib for red maple), LG 1.
Medium — 18 inches in dib, LG 2.
Small — 12 inches in dib, LG 3.

The changes in QI for these log classes—by species—between the two base periods were:

Species	*Large*	*Medium*	*Small*
White ash	-.09	-.05	-.03
Beech	+.01	+.03	+.06
Black cherry	+.01	+.02	+.07
Hard maple	-.01	+.02	+.04
Soft maple	.00	.00	+.03
Red oak	-.07	-.04	-.04
White oak	-.17	-.06	-.04
Yellow-poplar	-.03	.00	.00

In general, QI's increased for small logs, remained about the same for medium logs, and decreased for large logs; the greatest decrease was -0.17 for large white oak logs, the greatest increase was +0.07 for small black cherry logs. The average change in QI for all species and log classes was -0.0142.

We can gain better perspective of the importance of these changes in QI by translating them into dollars. At $200 per M bm No. 1C lumber, the maximum error from using QI's for 1964-68 would be (+) $34 per M bm for large white oak logs, and (-) $14 for small black cherry logs; the average error for the eight species and all log grades would be (-) $2.84 per M bm.

These revised QI tables will enable users of this log valuing system to update their log assessment procedures.

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APPENDIX

Tables 2 to 9 are based on 1970-74 lumber prices from the *Hardwood Market Report* for the Appalachian area; tables 10 to 16 are based on 1970-74 lumber prices from *The Commercial Bulletin* for the Appalachian area; and tables 17 to 22 are based on 1970-74 lumber prices from *The Commercial Bulletin* for the northeastern area.

Table 2.—*Quality index for WHITE ASH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.58
9	—	—	.59
10	—	0.81	.61
11	—	.83	.63
12	1.06	.86	.66
13	1.08	.88	.69
14	1.11	.90	.73
15	1.13	.93	.77
16	1.15	.96	.80
17	1.16	.98	.84
18	1.18	1.00	.88
19	1.20	1.03	.91
20	1.22	1.06	.95
21	1.23	1.09	.99
22	1.25	1.12	1.03
23	1.27	1.15	1.06
24	1.28	1.18	1.09

Table 3.—*Quality index for BEECH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.55
9	—	—	.56
10	—	0.69	.57
11	—	.70	.58
12	—	.71	.59
13	0.84	.72	.61
14	.87	.74	.62
15	.89	.77	.64
16	.90	.78	.65
17	.91	.79	.67
18	.91	.80	.69
19	.92	.81	.71
20	.92	.82	.73
21	.93	.83	.75
22	.93	.84	.77
23	.93	.84	.79
24	.93	.85	.82
25	.94	.85	.83

Table 4.—*Quality index for BLACK CHERRY by log grade or class and size class* [a]

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.52
9	—	—	.56
10	—	0.80	.60
11	—	.82	.63
12	—	.84	.66
13	1.11	.87	.69
14	1.12	.90	.73
15	1.12	.93	.77
16	1.13	.94	.82
17	1.14	.96	.86
18	1.15	.98	.89
19	1.16	1.00	.91
20	1.18	1.02	.92
21	1.19	1.04	.93
22	1.22	1.06	.94
23	1.24	1.09	.95
24	1.26	1.12	.96
25	1.28	1.15	.97

[a] Yield data from Hanks *(1965)*.

Table 5.—*Quality index for HARD MAPLE by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.49
9	—	—	.50
10	—	0.66	.50
11	—	.68	.50
12	—	.69	.50
13	0.99	.71	.51
14	.99	.73	.51
15	.99	.76	.51
16	1.00	.78	.52
17	1.01	.80	.53
18	1.02	.81	.55
19	1.03	.83	.57
20	1.04	.85	.59
21	1.06	.87	.61
22	1.08	.90	.63
23	1.10	.92	.65
24	1.12	.94	.67
25	1.14	.96	.69
26	1.15	.98	.71

Table 6.—***Quality index for RED OAK by log grade or class and size class***

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.50
9	—	—	.50
10	—	0.73	.51
11	—	.74	.51
12	—	.75	.51
13	0.96	.77	.51
14	1.03	.78	.51
15	1.06	.78	.51
16	1.08	.78	.52
17	1.09	.79	.53
18	1.09	.79	.54
19	1.10	.79	.56
20	1.09	.79	.59
21	1.10	.79	.61
22	1.09	.79	.64
23	1.10	.80	.68
24	1.10	.80	.72
25	1.11	.81	.76
26	1.11	.81	.76
27	1.12	.82	.77
28	1.14	.82	.77
29	1.14	.83	.78
30	1.16	.83	.78

Table 7.—***Quality index for SOFT MAPLE by log grade or class and size class***

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.50
9	—	—	.52
10	—	0.73	.54
11	—	.74	.56
12	—	.76	.59
13	0.92	.78	.62
14	.95	.79	.64
15	.97	.82	.67
16	.98	.84	.70
17	1.00	.86	.74
18	1.01	.88	.77
19	1.02	.91	.80
20	1.04	.93	.83
21	1.05	.96	.86
22	1.06	.99	.89
23	1.07	1.02	.92

Table 8.—***Quality index for WHITE OAK by log grade or class and size class***

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.46
9	—	—	.47
10	—	0.64	.49
11	—	.66	.50
12	—	.67	.52
13	0.90	.69	.53
14	.95	.71	.54
15	.99	.73	.56
16	1.02	.74	.57
17	1.05	.76	.59
18	1.07	.78	.62
19	1.09	.79	.64
20	1.10	.81	.67
21	1.11	.82	.69
22	1.13	.84	.72
23	1.15	.86	.75
24	1.18	.87	.77
25	1.21	.89	.80
26	1.24	.91	.82
27	1.27	.93	.84
28	1.30	.96	.86

Table 9.—***Quality index for YELLOW-POPLAR by log grade or class and size class***

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.51
9	—	—	.53
10	—	0.73	.54
11	—	.73	.56
12	—	.74	.57
13	0.87	.74	.59
14	.89	.75	.60
15	.91	.76	.62
16	.92	.77	.63
17	.93	.78	.65
18	.94	.79	.66
19	.96	.80	.68
20	.96	.80	.69
21	.98	.81	.71
22	.98	.82	.72
23	1.00	.82	—
24	1.00	.83	—
25	1.02	.84	—
26	1.02	.85	—
27	1.02	.85	—
28	1.03	.86	—
29	1.03	.87	—
30	1.03	.87	—

Table 10.—*Quality index for WHITE ASH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.56
9	—	—	.58
10	—	0.79	.59
11	—	.82	.61
12	1.05	.84	.64
13	1.08	.87	.68
14	1.10	.89	.71
15	1.12	.92	.75
16	1.14	.94	.79
17	1.16	.97	.83
18	1.18	1.00	.87
19	1.19	1.02	.90
20	1.21	1.05	.93
21	1.23	1.08	—
22	1.25	1.10	—
23	1.26	1.13	—
24	1.28	1.15	—

Table 11.—*Quality index for BEECH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.48
9	—	—	.49
10	—	0.63	.50
11	—	.64	.51
12	—	.66	.52
13	0.81	.67	.53
14	.83	.69	.55
15	.86	.72	.57
16	.87	.73	.58
17	.88	.74	.60
18	.88	.76	.62
19	.89	.77	.64
20	.89	.78	.67
21	.90	.79	.69
22	.90	.80	.72
23	.90	.80	.75
24	.91	.81	.78
25	.92	.82	—

Table 12.—*Quality index for BLACK CHERRY by log grade or class and size class* [a]

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.40
9	—	—	.46
10	-	0.74	.51
11	—	.77	.55
12	—	.79	.59
13	1.07	.82	.62
14	1.08	.86	.67
15	1.08	.89	.72
16	1.09	.91	.77
17	1.10	.93	.81
18	1.12	.95	.85
19	1.13	.97	.87
20	1.14	.99	.88
21	1.16	1.02	.90
22	1.18	1.04	.90
23	1.21	1.07	—
24	1.23	1.09	—
25	1.26	1.12	—

[a] Yield data from Hanks *(1965)*

Table 13.—*Quality index for HARD MAPLE by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
10	—	0.66	0.49
11	—	.67	.49
12	—	.69	.50
13	1.00	.71	.50
14	1.00	.73	.50
15	1.00	.76	.51
16	1.02	.78	.52
17	1.02	.80	.53
18	1.03	.81	.54
19	1.04	.83	.56
20	1.05	.85	.59
21	1.07	.87	.61
22	1.09	.89	.63
23	1.10	.92	.65
24	1.12	.94	—
25	1.14	.97	—
26	1.16	.99	—

Table 14.—*Quality index for RED OAK by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.50
9	—	—	.50
10	—	0.73	.50
11	—	.73	.51
12	—	.74	.51
13	0.95	.75	.51
14	1.02	.76	.51
15	1.04	.78	.52
16	1.07	.78	.52
17	1.08	.78	.53
18	1.08	.78	.54
19	1.08	.78	.56
20	1.08	.79	.59
21	1.08	.79	.62
22	1.08	.79	.65
23	1.09	.79	.68
24	1.09	.80	.72
25	1.09	—	.76
26	1.10	—	—
27	1.11	—	—
28	1.12	—	—
29	1.13	—	—
30	1.14	—	—

Table 15.—*Quality index for WHITE OAK by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.40
9	—	—	.42
10	—	0.59	.43
11	—	.61	.45
12	—	.63	.46
13	0.87	.65	.48
14	.92	.67	.49
15	.96	.69	.51
16	.99	.71	.53
17	1.02	.73	.55
18	1.04	.75	.57
19	1.06	.76	.60
20	1.07	.78	.62
21	1.08	.79	.65
22	1.10	.81	.68
23	1.12	.83	.71
24	1.15	.84	.74
25	1.18	.86	.77
26	1.21	.88	.80
27	1.24	.90	—
28	1.27	.94	—

Table 16.—*Quality index for YELLOW-POPLAR by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.49
9	—	—	.50
10	—	0.72	.52
11	—	.72	.54
12	—	.72	.55
13	0.86	.72	.57
14	.88	.73	.58
15	.90	.75	.60
16	.91	.76	.62
17	.92	.77	.63
18	.94	.78	.65
19	.95	.78	.66
20	.96	.79	—
21	.97	.80	—
22	.98	.80	—
23	.99	.81	—
24	1.00	.81	—
25	1.00	.82	—
26	1.01	.82	—
27	1.02	.83	—
28	1.02	.84	—
29	1.02	.85	—
30	1.03	.86	—

Table 17.—*Quality index for ASH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.50
9	—	—	.51
10	—	0.77	.53
11	—	.80	.55
12	1.02	.82	.58
13	1.05	.85	.62
14	1.07	.87	.66
15	1.09	.90	.70
16	1.11	.92	.74
17	1.13	.95	.78
18	1.14	.97	.82
19	1.16	1.00	.85
20	1.18	1.02	.89
21	1.19	1.05	.92
22	1.21	1.07	.95
23	1.22	1.09	.98
24	1.24	1.11	1.01

Table 18.—*Quality index for BEECH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.48
9	—	—	.49
10	—	0.63	.50
11	—	.64	.51
12	—	.66	.52
13	0.81	.67	.54
14	.83	.70	.55
15	.86	.72	.57
16	.87	.73	.59
17	.88	.75	.61
18	.89	.76	.62
19	.89	.77	.65
20	.90	.78	.67
21	.91	.79	.69
22	.91	.80	.72
23	.91	.81	.75
24	.92	.81	.78
25	.93	.82	.80

Table 19.—*Quality index for BIRCH by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.48
9	—	—	.48
10	—	0.68	.48
11	—	.70	.48
12	—	.73	.48
13	0.97	.75	.49
14	1.00	.77	.49
15	1.03	.78	.49
16	1.07	.81	.50
17	1.14	.84	.51
18	1.18	.86	.52
19	1.24	.88	—
20	1.28	.90	—
21	1.32	.93	—
22	1.36	.95	—
23	1.38	.97	—
24	1.40	1.00	—

Table 20.—*Quality index for HARD MAPLE by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.57
9	—	—	.57
10	—	0.72	.58
11	—	.74	.58
12	—	.75	.58
13	1.03	.77	.59
14	1.03	.79	.59
15	1.03	.81	.60
16	1.04	.84	.60
17	1.05	.85	.61
18	1.06	.86	.63
19	1.07	.88	.64
20	1.08	.90	.67
21	1.10	.92	.68
22	1.12	.94	.70
23	1.13	.96	.71
24	1.16	.98	.73
25	1.17	1.00	.74
26	1.19	1.02	.76

Table 21.—*Quality index for SOFT MAPLE by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.54
9	—	—	.56
10	—	0.75	.57
11	—	.77	.59
12	—	.78	.62
13	0.96	.80	.64
14	.98	.82	.67
15	1.00	.84	.70
16	1.02	.86	.72
17	1.04	.89	.76
18	1.05	.91	.79
19	1.07	.94	.81
20	1.08	.96	.84
21	1.10	.99	.87
22	1.11	1.01	.89
23	1.12	1.04	—

Table 22.—*Quality index for OAK by log grade or class and size class*

Log diameter inside bark (inches)	Quality index		
	Log grade No. 1	Log grade No. 2	Log grade No. 3
8	—	—	0.55
9	—	—	.55
10	—	0.75	.55
11	—	.75	.55
12	—	.76	.56
13	0.94	.77	.56
14	1.00	.78	.56
15	1.03	.79	.56
16	1.05	.80	.56
17	1.06	.80	.57
18	1.06	.80	.59
19	1.06	.80	.60
20	1.06	.80	.62
21	1.06	.80	.65
22	1.06	.81	.68
23	1.07	.81	.71
24	1.07	.81	.74
25	1.08	.81	.78
26	1.09	.81	—
27	1.09	.81	—
28	1.10	.82	—
29	1.11	.82	—
30	1.12	.82	—

Mendel, Joseph J., and Margaret K. Peirsol.
1977. **Quality index tables for some eastern hardwood species.**
Northeast. For. Exp. Stn., Upper Darby, Pa.
10 p. (USDA For. Serv. Res. Pap. NE-370)

Revised quality index (QI) tables for white ash, beech, black cherry, birch, hard maple, soft maple, red oak, white oak, and yellow-poplar are based on 1970-74 lumber prices for the Appalachian and northeastern marketing areas. Changes in QI since 1964-68 were greatest for white oak; there also were significant changes in QI for red oak, white oak, and yellow-poplar.

854.2:832.10:651.7:(083.7):176.1(74)(77)

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INTENSIVE CULTURE ON NORTHERN FOREST-INDUSTRY LANDS:

Trends, Expectations, and Needs

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by David A. Gansner
Owen W. Herrick
Dietmar W. Rose

USDA FOREST SERVICE RESEARCH PAPER NE-371
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
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The Authors

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MANUSCRIPT RECEIVED FOR PUBLICATION 6 JULY 1976

ABSTRACT

Results of a survey of intensive forest-culture practices on forest-industry lands in the North. Timber-stand improvement and commercial thinning have been and apparently will continue to be the most popular practices undertaken. Estimated increases in recent annual harvests due to intensive culture averaged about 4 percent, and greater increases are expected during the next decade. Industrial managers expressed a high-priority need for more knowledge about genetic tree improvement, site preparation, fertilization, and species conversion.

KEYWORDS: cultural practices, industrial forestry, investments, research needs.

ONE WAY TO INCREASE wood supplies is to invest in intensive-culture practices that accelerate forest growth. The fact that National Forest and nonindustrial private lands *could* provide much additional wood through intensified forest management has been well documented *(U.S. Forest Service 1973).* Yet opportunities for intensive culture on industrial ownerships have received relatively less emphasis in recent studies of the timber situation.

There are obvious reasons for this. Because of their higher relative productivity, industry lands have been more amenable to intensive culture than have forest lands in other ownership categories. There is also a high degree of owner control on industry lands, and a record of substantial investments in recent years. Thus the ability and motivation to apply intensive culture techniques are greatest for the industrial ownership.

Intensive forest culture includes control of growing stock, fertilization, site preparation, species conversion, tree improvement, weed control, drainage, and short-rotation or silage forestry. (See appendix for definitions of practices considered in this study.) Effective use of these techniques requires a knowledge of how and where to apply them as well as the ability and desire to invest.

To evaluate trends of and needs for intensive culture on forest industry lands, and to determine potential impacts on future wood supplies, an industry-wide survey was conducted in 1975 *(DeBell 1976).* The survey included 41 industrial firms having registered Tree Farms or more than 50,000 acres of forest land in the Northeastern or North Central United States; 76 percent of the firms responded.

As part of the nationwide survey, our report focuses on the northern forest industry's experience with intensive-culture activities, forecasts of anticipated activies, and corresponding impacts on wood supplies. A better understanding of forecast and potential increases in wood supply from intensive culture of industry forests should facilitate decisions about what may be possible on lands of other ownership classes.

BACKGROUND

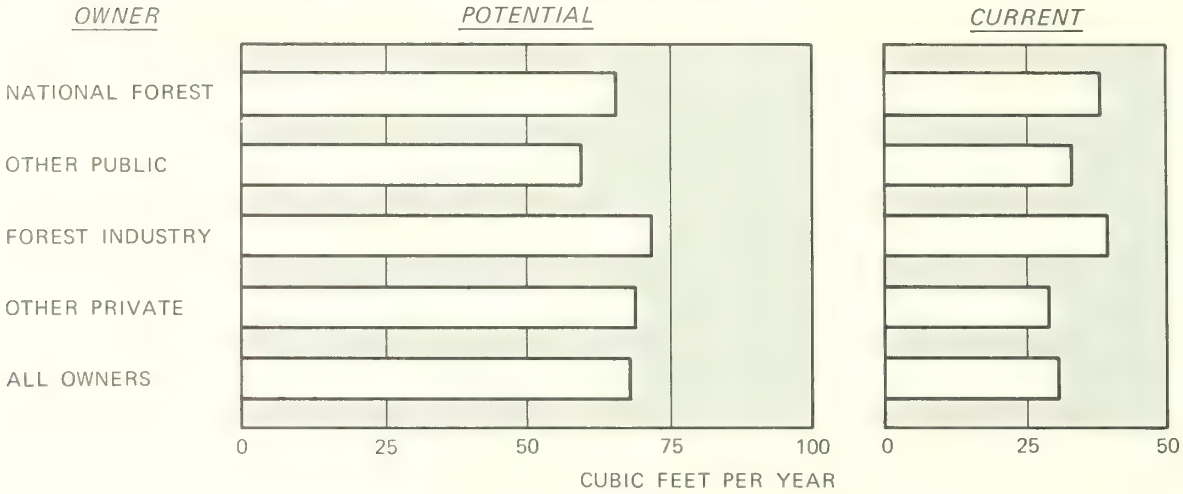
Average net growth figures for northern forests reflect a high proportion of land in lower productivity classes, the predominance of slow-growing hardwood stands, and the presence of considerable low-quality timber. In spite of recent substantial increases, net growth of timber is still much less than the potential yields attainable in fully-stocked natural stands (fig. 1). Even higher yields can be attained in stands under intensive management by use of genetically improved trees, fertilization, and spacing control.

In terms of inherent productivity, industry lands are of better quality than those in any other ownership class (fig. 1). This is one reason why intensive management is practiced most on those lands—it pays best. This also suggests that industry lands will have an absolute advantage for any future investments. Thus the expectations of industrial owners might be considered as the upper limit of what might be accomplished by other classes of owners.

To get a feeling for the intensive-culture/wood-supply relationships, managers of industrial forest land were asked a series of questions about:

- Trends in recent past (1971-74) and anticipated future (1975-85) use of 12 intensive-culture practices,
- Estimated impact of intensive-culture practices on recent past and future timber harvests,
- Information base used by the firm in making investment decisions on intensive-culture practices; that is, the source and quality of information and the manager's suggestions about priorities for future research and development programs.

Figure 1.—Potential and current net growth per acre in the North, 1970. Source: U.S. Forest Service *(1973)*. Potential growth is defined as the average net growth attainable in fully stocked natural stands. Greater growth can be attained in intensively managed stands.



RESULTS

Trends in Intensive-Culture Activities

Managers were asked to estimate the percentage of company land treated with specific cultural practices each year for the 1971-74 period. They were also asked to indicate the firm's intentions for the next decade (1975-85) for each cultural practice: increase use; decrease use; use it the same amount; or do not use it at all.

Averages for percentage of land area treated were weighted by acreage size class of individual firms (table 1). In viewing these percentages, keep in mind that most practices are applicable to or needed on only a portion of a company's land. Thus a small percentage of land treated may be rather significant in terms of accomplishing the needed task.

Application of timber-stand improvement, commercial thinning, and site preparation increased during the 1971-74 period; and greater activity is anticipated for most practices during the next decade. Exceptions to these trends are irrigation, drainage, silage forestry, precommercial thinning, and fertilization where past use was negligible and little use is anticipated in the near future.

As a percentage of northern forest-industry land treated annually, timber-stand improvement and commercial thinning were the major cultural practices undertaken. Most firms intend to maintain or increase their investments in these practices.

Firms that have less than 50,000 acres are doing weed control, species conversion, drainage, and genetic improvement on a greater share of their acreage than are larger firms (table 2). Otherwise, no distinct relationship is apparent between recent management intensity and ownership size class. Most managers anticipate increased activity in timber-stand improvement, commercial thinning, and genetic-improvement practices. For precommercial thinning, fertilization, and weed-control activities, the amount of planned future activity increases with ownership size class.

Impact on Wood Supplies

Using 1970 as a base for comparison, industrial managers estimated the actual increases (1971-74) and anticipated increases (1975-85) in annual harvests attributable to intensive-culture practices on company lands. Implicitly, these estimates have been adjusted for increased harvesting due to factors other than increased growth associated with intensive culture; for example, from more complete

Table 1. ***Trends in intensive forest-culture activities; Northern forest-industry averages***

[In percentage of land area treated]

Cultural practice	1971	1972	1973	1974	1971-74	Percentage of all firms intending to maintain or increase use of practice (1975-85) [a]
Precommercial thinning	([b])	([b])	([b])	([b])	0.1	32
Timber-stand improvement	2.3	2.3	2.8	3.3	10.6	74
Commercial thinning	1.0	1.1	1.1	1.1	4.2	81
Fertilization	0	([b])	0	0	([b])	39
Site preparation	.1	.1	.2	.2	.6	55
Species conversion	.1	.1	.1	.1	.4	58
Genetic improvement	([b])	([b])	([b])	([b])	([b])	61
Weed control	.1	.1	.2	.1	.5	52
Short rotation or silage	0	0	0	([b])	([b])	26
Drainage	0	0	0	([b])	([b])	19
Irrigation	0	0	0	0	0	3
Intensified protection	.8	.9	.8	.9	([c])	52

[a] Remaining firms indicated that they would either decrease present use or not use practice at all.
[b] <0.1 percent.
[c] Not additive.

able 2.—***Intensive forest culture activities; Northern forest industry averages by acreage size class***

tural practice	Less than 50 thousand acres		50-250 thousand acres		More than 250 thousand acres	
	Industrial land treated (1971-74)	Percentage of all firms intending to maintain or increase use of practice (1975-85) [a]	Industrial land treated (1971-74)	Percentage of all firms intending to maintain or increase use of practice (1975-85) [a]	Industrial land treated (1971-74)	Percentage of all firms intending to maintain or increase use of practice (1975-85) [a]
	Percent					
commercial thinning	0	20	0.4	31	([b])	40
ber-stand improvement	5.7	80	3.9	69	12.5	70
mercial thinning	5.4	60	5.8	94	3.8	60
ilization	0	20	([b])	38	0	50
preparation	0	20	2.0	69	.2	50
cies conversion	2.0	40	.9	63	.2	50
etic improvement	.2	60	([b])	56	([b])	60
d control	4.9	40	1.8	50	.1	50
rt rotation or silage	0	60	([b])	19	0	20
inage	1.4	40	0	19	0	10
gation	0	0	0	6	0	0
nsified protection	([c])	60	([c])	31	([c])	60

Remaining firms indicated that they would either decrease present use or not use practice at all.
<0.1 percent.
Not additive.

utilization in harvesting, and for certain culture activities that do not result in increased yield, but do attain such objectives as increased product quality or changed species composition.

The estimated increases in annual harvest due to intensive culture on northern forest-industry lands, weighted by 1970 harvest figures, are as follows:

Period	*Estimated increase due to intensive culture*		*Total roundwood harvest on northern industry lands in 1970*[b]	*Additional annual wood supplies*
	Range	*Average*[a]		
	(percent)		*(million cu. ft.)*	
1971-74	0-20	3.8	316	12
1975-85	0-40	8.9		28

---

[a] Weighted by 1970 harvest of responsing firms.

[b] Source: U.S. Forest Service 1973

Recent (1971-74) increases in annual harvest from industrial lands due to intensive-culture practices were estimated to be 4.5 percent on a nationwide basis. Estimates from the North were somewhat less (3.8 percent), presumably because northern forests have a high proportion of land in lower productivity classes and slow-growing hardwood stands.

As a result of applying intensive forest-culture practices, future (1975-85) increases of 14.0 percent are expected in annual roundwood harvests from industry lands across the nation. Managers of industry lands in the North are forecasting a much lower percentage increase, averaging 8.9 percent.

Although the increase forecast represents a substantial contribution to harvests from northern forest-industry lands, it will be less evident as part of the total wood harvest in the North. If 1970 harvest figures for all forest ownerships are used as a base, the forecast harvest from industry lands *due to intensive-culture practices* will increase total annual northern wood harvest by no more than 2 percent in the next decade.

The expectations from forest-industry lands may well indicate the practicable limits of accomplishment for investment in intensive-culture practices on other forest ownerships. Corresponding increases in northern wood harvest for the other ownerships would be 1 percent (20 million cubic feet) from National Forest and other public lands, and 6 percent from other private lands. Such increases are not very likely, however. For these ownerships the objectives, motivation, and opportunities for timber-growing make probable less implementation of intensive-culture practices than the forest industry is willing to undertake.

Information Base for Decisions

Managers were asked four questions about the information base used to make decisions about investments in intensive-culture practices. Two of the questions dealt with sources of information: is this information developed internally or outside the organization?; and what are the sources of outside information? The other two were concerned with adequacy of information: what is the quality of current information about specific practices?; and where should priorities for future research and development be put?

Most northern firms depend on sources outside the organization for information about new or little-used practices such as short-rotation or silage forestry, intensified protection, genetic improvement, and drainage (fig. 2). But decisions on traditional practices of growing-stock control, such as commercial and precommercial thinning, timber-stand improvement, and species conversion are based primarily on knowledge developed within the company.

Very few firms use consultants (fig. 3). State, university, and U.S. Forest Service research organizations are their principal sources for outside information. Most companies are involved in cooperative research programs. Cooperative ventures with universities and the Forest Service are common in the North.

Responses to questions about the adequacy of current information and priorities for research and development of cultural practices are summarized in figure 4. At least half the respondents felt that information available about irrigation, drainage, short rotation or silage forestry, and fertilization practices is, at best, poor. However, only one of these practices—fertilization—ranks high on their list of priorities for research and development. More than 40 percent of the respondents indicated a high-priority need for more knowledge about genetic improvement, site preparation, fertilization, and species conversion. Most firms felt that the quality of information available about commercial thinning and timber-stand improvement is rather good, but they still want to see more research and development of these two relatively popular practices.

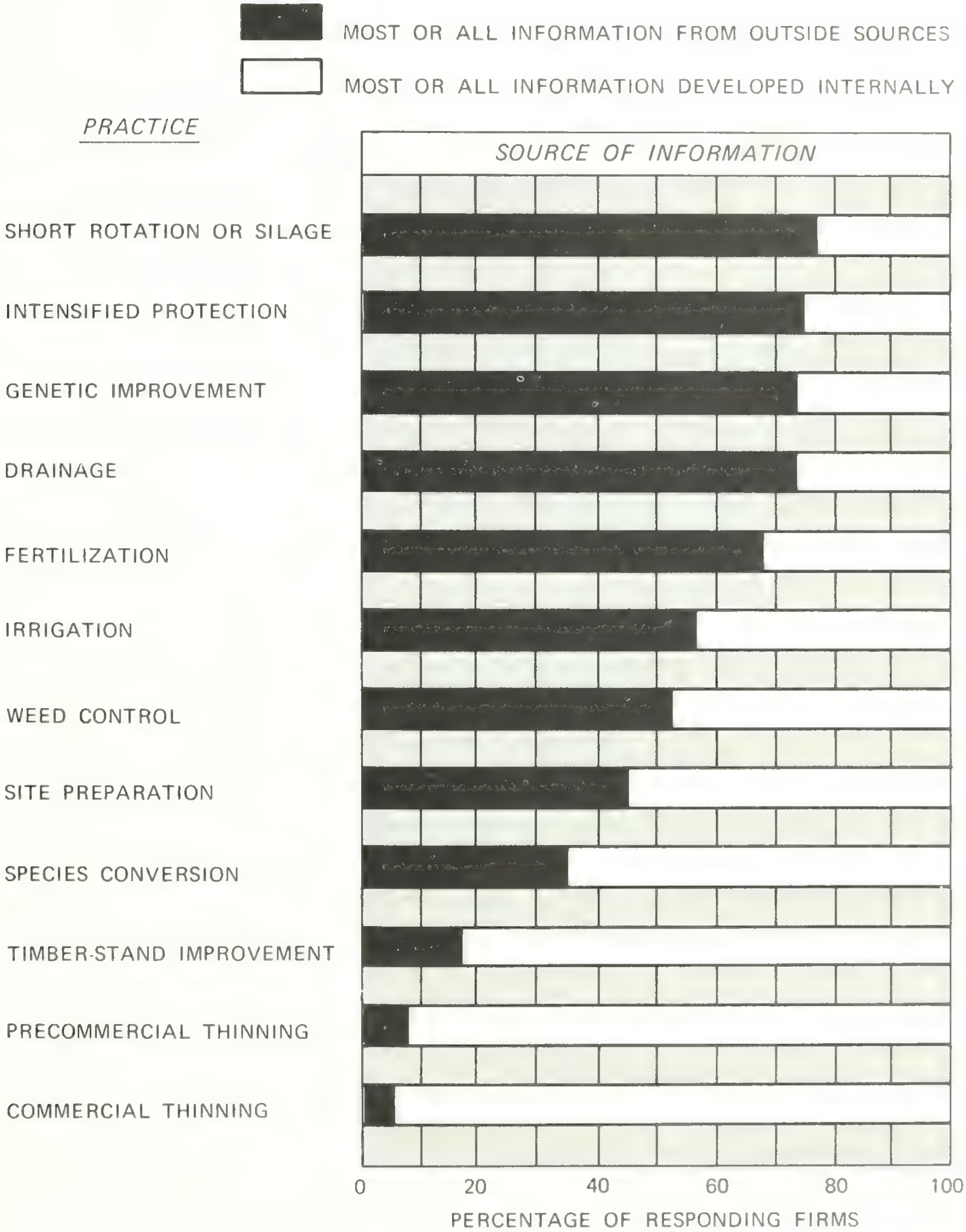
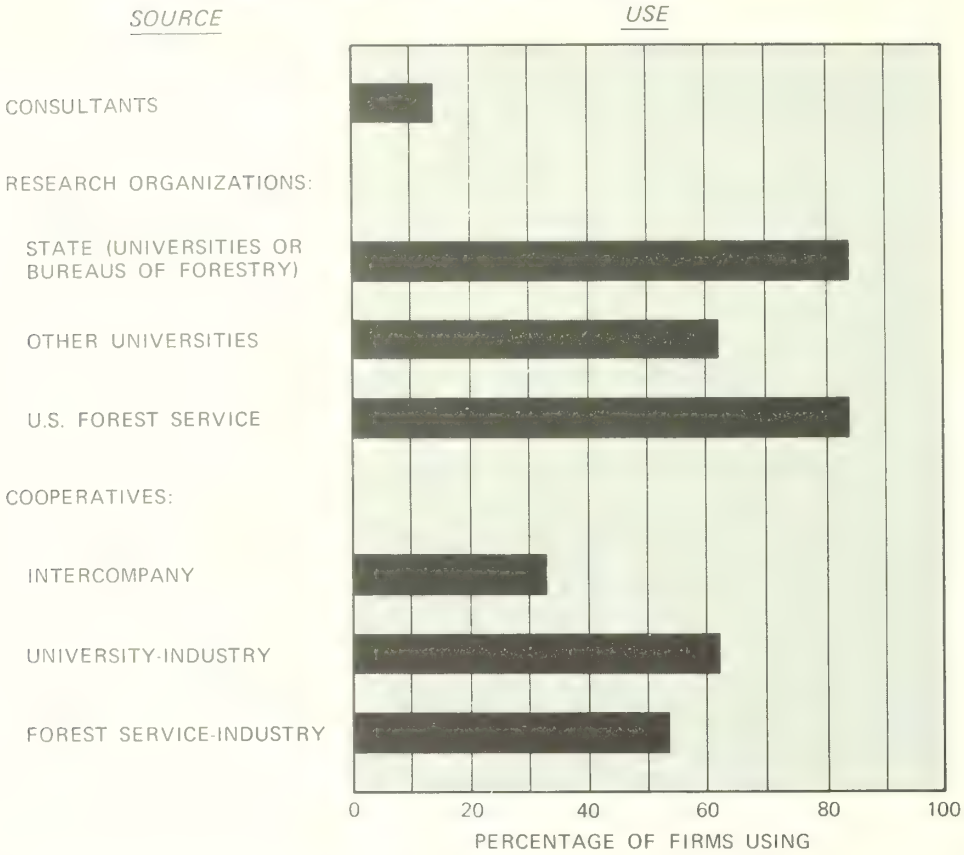


Figure 3.—Source of outside information for decisions about intensive-culture practices in the North.



SUMMARY

Study results provide an up-to-date look at the trends in application and timber-supply potential associated with intensive-culture practices on forest-industry lands in the North. They give us valuable insight for assessing the role of forest-industry landowners as suppliers of timber and for identifying the needs and priorities for future research. Key findings for northern forest-industry lands are:

- Applications of timber-stand improvement, commercial thinning, and site preparation have increased in recent years.
- Timber-stand improvement and commercial thinning have been and will continue to be the most popular practices undertaken.
- Greater activity is anticipated for most practices during the next decade; exceptions are drainage, irrigation, silage forestry, precommercial thinning, and fertilization.
- Estimated increases in recent annual harvests due to intensive culture averaged about 4 percent.
- During the next decade, increases in annual harvests due to intensive culture are expected to average about 9 percent.
- Increased harvests from intensive culture on industrial lands will increase total annual wood harvest in the North by no more than 2 percent in the next decade.
- Industrial managers express a high-priority need for more knowledge about genetic tree improvement, site preparation, fertilization, and species conversion.

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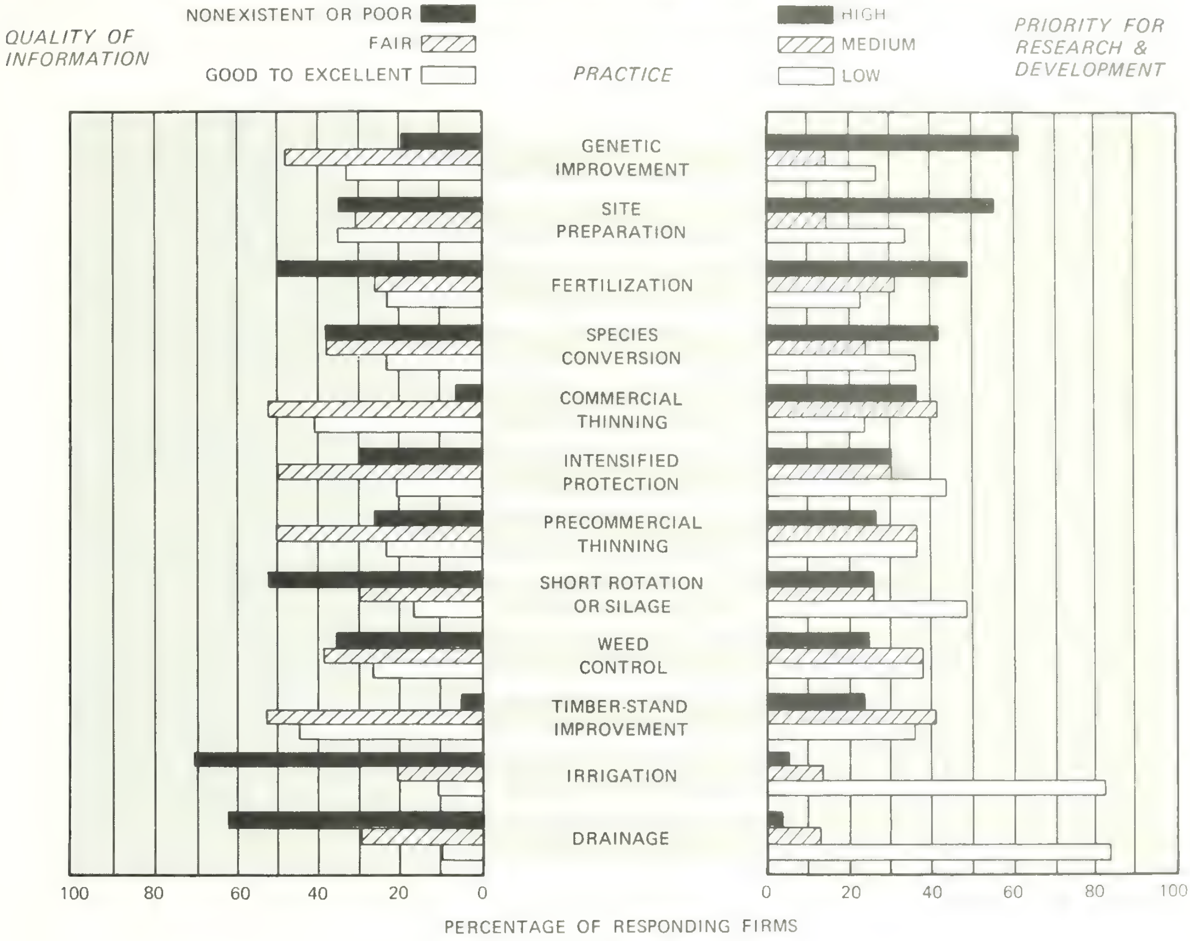
Figure 4.—Quality of current information and priorities for research and development of intensive-culture practices in the North.



APPENDIX

Practices Considered in This Study

Precommercial thinning.—A thinning made in immature stands for the purpose of increasing the growing-space of residual trees. No merchantable products are removed.

Timber-stand improvement.—This includes treatments imposed on intermediate-age stands to improve stand composition, condition, or growth rate. It may be accomplished by cutting, girdling, or poisoning of undesirable trees.

Commercial thinning.—This differs from precommercial thinning in that merchantable products are removed in the thinning; It also may be done to salvage merchantable stems that would be lost through mortality.

Fertilization.—Application of fertilizers to forest stands for the purpose of accelerating their growth rate.

Site preparation.—Action taken for the primary purpose of improving survival and growth rate of a new stand. Site preparation includes prescribed fire, herbicide application, and various mechanical measures; it does *not* include broadcast burning done primarily for fuel reduction or slash disposal.

Species conversion.—Actions taken to change the composition of a stand from one species type to another (for example, from hardwood to pine).

Genetic improvement.—Any of several approaches aimed at improving the quality of reproductive material (seeds, cuttings, seedlings) used in establishing new stands.

Weed control.—Operations aimed at suppressing or eliminating competition from undesirable vegetation during the early stages of a forest crop. Weed control includes cultivation and application of herbicides (including release of conifers from brush and hardwood competition).

Short-rotation or silage.—Coppice management of hardwoods at close spacing; for example, sycamore silage on rotations or cutting cycles of 10 years or less.

Drainage.—Removal of excess water from sites to enhance survival and growth of forest crops.

Irrigation.—Addition of water to sites for the purpose of increasing growth of forest crops.

Intensified protection.—Includes special measures to reduce losses associated with disease, insects, animals, and fire. Standard fire protection does not qualify as intensified protection.

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- Warren, Pennsylvania.

Gansner, David A., Owen W. Herrick, and Dietmar W. Rose.
1977. **Intensive culture on northern forest-industry lands: trends, expectations, and needs.** Northeast. For. Exp. Stn., Upper Darby, Pa.
8 p., illus. (USDA For. Serv. Res. Pap. NE-371)

Timber-stand improvement and commercial thinning are the practices most often used, and probably will continue to be. Increases in recent harvests due to intensive culture were estimated at about 4 percent. Managers expressed needs for more knowledge about genetic tree improvement, site preparation, fertilization, and species conversion.

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Effect of Strip Mining on Water Quality in Small Streams in Eastern Kentucky, 1967-1975

by Kenneth L. Dyer
and Willie R. Curtis

USDA FOREST SERVICE RESEARCH PAPER NE-372
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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Effect of Strip Mining on Water Quality in Small Streams in Eastern Kentucky, 1967-1975

ABSTRACT

Eight years of streamflow data are analyzed to show the effects of strip mining on chemical quality of water in six first-order streams in Breathitt County, Kentucky. All these watersheds were unmined in August, 1967, but five have since been strip mined. The accumulated data from this case history study indicate that strip mining causes large increases in the concentrations of most major dissolved constituents in the runoff waters, the concentration of most of these reaching a maximum some time after mining has ceased, then holding steady for several years. The maximum concentration of dissolved salts occured during the low flow of the dormant season, whereas maximum salt loads occurred during the high flow of the early part of the growing season.

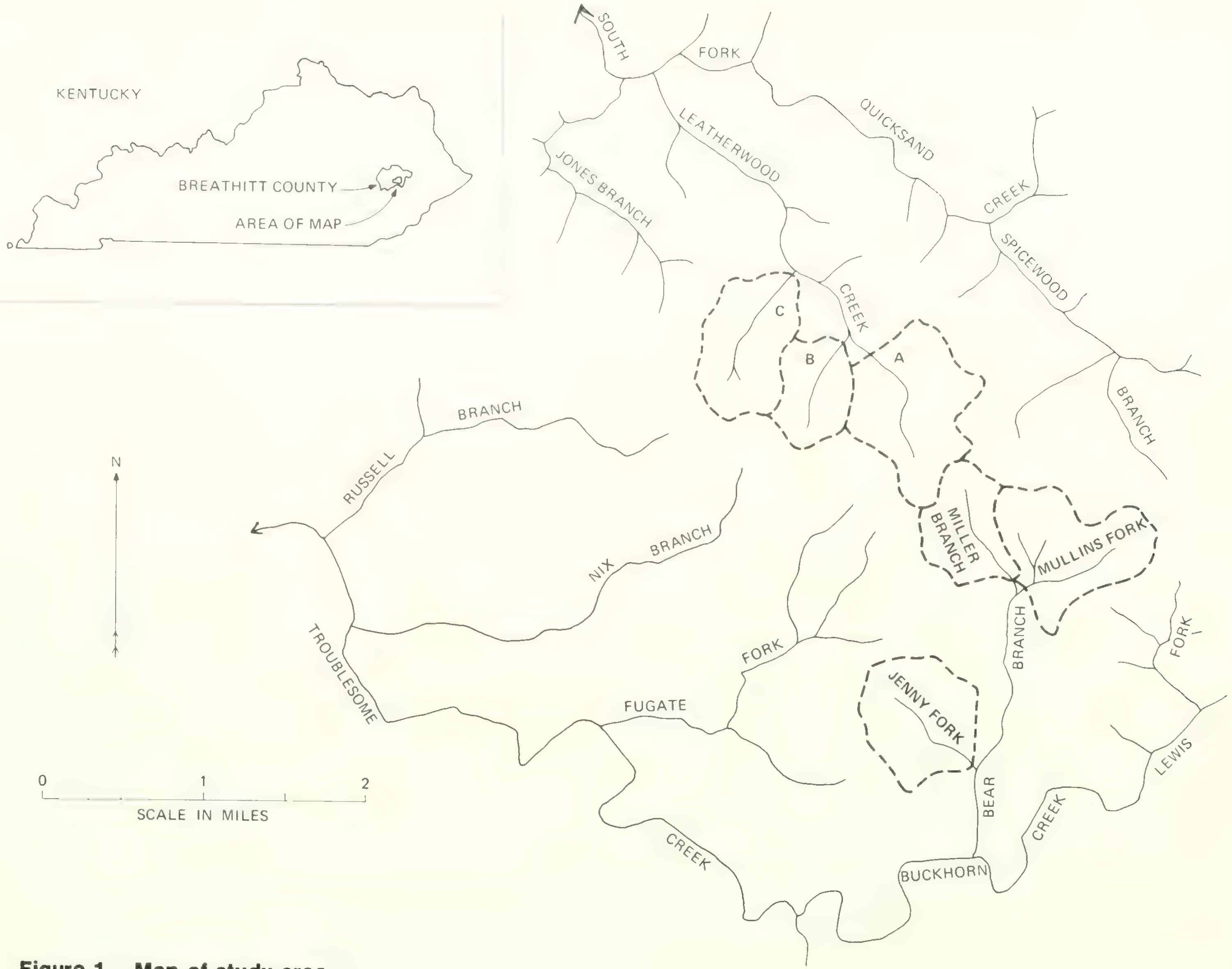

Figure 1.—Map of study area.

STREAM pH values increased from about 6.8 before mining to about 7.4 after strip mining. Acid is formed in the mine spoils of these watersheds, but it is neutralized by contact with spoil, soil, subsoil or aquifer materials before it can enter the streams. Other chemical parameters investigated include Ca, Mg, Na, K, Fe, Al, Mn, Zn, SO_4, Cl, HCO_3 and specific conductance. The salt concentrations and loads in streams draining mine spoils are largely dependent on (1) the rate of pyrite decomposition on the watershed, (2) the chemical nature of the spoil, soil, and aquifer materials contacted by the acid drainage water, and (3) the supply of water available for salt transport and the seasonal distribution of this supply of water.

REVIEW OF METHODS AND EARLIER OBSERVATIONS

Strip mining for coal in Appalachia can have a profound effect on the quality of water downstream from the mining operation. The same may be said of road building, or of any other activity in which large quantities of earth are moved. To evaluate the impact of strip mining on the environment, a case history study of six first-order watersheds ranging in size from 172 to 380 acres was initiated in 1967 (see figure 1 for location map). The three Leatherwood Creek watersheds are separated from the three Bear Branch watersheds by a narrow ridge. The watersheds are adjacent or nearly so and are similar in all respects except aspect; they range in elevation from 800 to 1,500 feet. Average stream slope is 4 percent and average slope of the land is about 30 percent. Three minable coal beds outcrop at altitudes of approximately 1,350, 1,380, and 1,420 feet. There had been a limited amount of deep mining on Miller Branch many years earlier, but any effects of this mining on water quality were not apparent at the beginning of this study in 1967. The area of each watershed and the percentage of it disturbed by mining at different times are given in table 1.

No mining is presently underway on any of the six watersheds. All the spoils have been smoothed and seeded and are now revegetated. There was apparently little attempt made to cover the entire spoil with material from any one stratum, as evidenced by the great variety in type and density of vegetation that now covers these spoils, as well as by the sharp transitions that separate the vegetation zones.

Data collected from the beginning of the study in November 1967 include stream discharge (continuous), precipitation (continuous), temparature, turbidity, specific conductance, pH, and concentrations of sediment, sulfate, bicarbonate, carbonate, calcium, magnesium, aluminum, manganese, zinc, iron, and copper. When no trace of copper was found over a 2-year

Table 1.—*Physical characteristics of the six watersheds*

Watershed	Acreage	Percentage of land disturbed on			
		4 Feb 1968	9 Oct 1969	20 Oct 1972	30 Oct 1975
Leatherwood Creek					
A	380	0	53	67	67
B	172	0	40	71	71
C	283	17	17	39	39
Bear Branch					
Jenny Fork	287	0	0	0	0
Miller Branch	190	0	29	55	55
Mullins Fork	327	0	7	46	46

period, tests for that element were discontinued. Tests for potassium were begun at that time and tests for chloride and sodium were begun in 1973. Water samples were collected weekly until the end of January 1972 in the Leatherwood Creek watersheds and until the end of October 1972 in the Bear Branch watersheds, after which samples were collected every 4 weeks in both watersheds. Samples were again collected weekly during the 1975 water year (Nov. 1, 1974 to Oct. 31, 1975) on the Bear Branch watersheds. Water quality data are still being collected from all six streams. It was necessary to abandon gages at all three Leatherwood Creek watersheds at the end of the 1971 water year, because a dam constructed downstream obstructed access to them. The three tributaries to Bear Branch (Jenny Fork, Miller Branch, and Mullins Fork) are still being gaged.

Contour strip mining was started on the Leatherwood C watershed on 15 August 1967 and on four other watersheds on or after 1 May 1968. Jenny Fork has still not been mined and serves as a reference or undisturbed watershed. At least 6 months of baseline data were collected on four of the watersheds before they were mined. Both contour stripping and mountaintop removal were used in four of the watersheds, but only contour stripping was used on Miller Branch. The period of active mining on the watersheds ranged from about 1 to 5-1/2 years.

Earlier work in these watersheds by Curtis *(1972a, 1973)* showed that mining increased the concentrations of sulfate, calcium, magnesium, aluminum, manganese, iron, and zinc in streams. He observed that the concentrations of some elements increased to a plateau immediately after the mining, whereas others continued to increase gradually for at least 2 years after mining had ceased. He noted that, although aluminum and manganese concentrations in stream water increased immediately after mining, they returned to normal within a year after mining had stopped. Curtis *(1974)* found that erosion and sedimentation in this area also increased sharply after strip mining, with about half the total sediment yield in the first 6 months. Erosion and sediment yield then declined quickly, having a half-life of about 6 months. Peak streamflow rates increased by a factor of 3 to 5 after surface mining *(Curtis 1972b)*. Branson and Batch *(1971)* studied the effect of mining on fish populations in these streams. They found that the siltation and turbidity associated with strip mining severely reduced the number of benthic food organisms and affected breeding, thus eliminating some species of fish from the affected streams and severely reducing the populations of others.

GEOLOGY

Detailed geologic maps of the Leatherwood Creek and Bear Branch watersheds are not available; however, much of the information published for the nearby Haddix quadrangle *(Mixon 1965)* should be applicable. It appears that the mountaintop removal and deep bench cuts at an altitude of approximately 1,400 feet mark areas in which coal has been mined from the Upper Knob coal zone. The line of strip mine benches or terraces, about 50 feet lower in elevation, probably marks the Lower Knob coal zone. Strata associated with the coal in these zones include sandstone, siltstone, shale, limestone, and underclay. Limestone was reported from only one location in the Haddix quadrangle; however, fragments of a similar gray limestone were observed by the authors in the mine spoil along the divide between Leatherwood Creek and Bear Branch.

WATER QUALITY

All water-quality and discharge data for each watershed have been summarized for the 1968 through 1975 water years and are presented in table 2. Except for pH values, these averages show mean concentrations for each year on a time basis. The pH values were computed from the mean annual hydrogen ion concentrations. The mean concentrations of dissolved solids are considerably higher than those that would have been found had they been calculated as discharge weighted averages, because most of the annual flow occurs in less than 10 percent of the time and is relatively low in dissolved solids. For sediment, the opposite relationship holds true: sediment concentrations generally increase at an even faster rate that does discharge.

To show seasonal changes and long-term trends graphically in each of the six watersheds, calcium, magnesium, sulfate, and bicarbonate concentrations in monthly water samples were plotted with the accompanying discharge data in figures 2 through 7. These first-order streams

TEXT CONTINUES ON PAGE 10.

Table 2.—*Summary of annual water-quality and discharge data for individual watersheds, 1968-1975 water years*

Item	Water Year	Bear Branch			Leatherwood		
		Jenny	Miller	Mullins	A	B	C
Discharge (inches)	1968	--	--	--	25.8	27.9	24.7
	1969	11.2	12.6	9.7	11.3	11.7	12.4
	1970	17.6	24.2	16.6	28.2	31.1	19.3
	1971	27.0	35.2	26.5	24.5	32.3	24.4
	1972	34.3	--	31.5	--	--	--
	1973	25.0	23.4+	28.2	--	--	--
	1974	29.3	31.5	33.7	--	--	--
	1975	--	--	--	--	—	--
Turbidity (J.T.U.)	1968	28	17	37	82	114	147
	1969	26	15	100	160	177	45
	1970	19	255	202	127	185	44
	1971	25	466	76	125	179	36
	1972	16	888	205	395	265	31
	1973	11	69	111	128	361	17
	1974	9	45	190	107	112	33
	1975	18	188	125	316	239	5
Conductivity (micromhos/cm)	1968	80	55	58	51	76	92
	1968	80	65	79	100	177	138
	1970	83	145	131	224	250	203
	1971	62	245	102	298	294	385
	1972	85	235	156	297	495	424
	1973	78	317	319	381	664	525
	1974	72	318	424	404	947	568
	1975	73	298	438	388	759	550
pH[a]	1968	6.3	6.5	6.3	6.6	6.5	6.4
	1969	7.0	6.9	6.8	7.0	7.2	7.2
	1970	7.1	7.0	7.1	7.2	7.4	7.2
	1971	7.1	7.3	7.3	7.4	7.5	7.3
	1972	6.6	7.0	6.9	7.1	7.3	6.9
	1973	6.7	7.5	7.5	7.4	7.4	7.2
	1974	6.9	7.4	7.5	7.3	7.5	7.3
	1975	6.8	7.4	7.6	7.4	7.4	7.1
Sulfate	1968	11	7	6	10	11	21
	1969	14	6	7	11	34	33
	1970	15	32	14	81	68	88
	1971	12	77	12	98	81	160
	1972	23	66	17	95	165	169
	1973	16	81	49	125	252	213
	1974	11	79	91	135	426	258
	1975	17	78	103	137	392	251
Chloride (ppm)	1973	4.4	4.5	4.3	4.6	5.1	5.3
	1974	3.2	4.1	5.0	4.4	5.3	4.3
	1975	2.3	2.5	3.0	2.7	3.6	2.7
Bicarbonate (ppm)	1968	22	18	22	15	23	17
	1969	22	25	33	36	57	31
	1970	19	31	46	45	72	34
	1971	15	44	37	49	77	34
	1972	16	56	66	56	83	41
	1973	17	83	105	65	90	41
	1974	14	82	135	72	103	40
	1975	12	101	172	69	91	47
Calcium (ppm)	1968	5.8	3.8	3.8	3.4	5.3	6.7
	1969	6.1	4.7	5.1	6.6	14.0	10.4
	1970	6.5	10.2	8.9	15.5	21.6	13.4
	1971	4.8	19.9	7.3	24.4	31.3	48.5
	1972	6.2	17.4	11.1	23.3	49.6	47.1
	1973	5.3	29.7	27.7	37.0	79.9	67.2
	1974	3.5	26.8	34.7	35.2	117.7	70.4
	1975	4.5	31.2	46.0	38.8	106.2	68.7

continued

Table 2.—*continued*

Item	Water Year	Bear Branch			Leatherwood		
		Jenny	Miller	Mullins	A	B	C
Magnesium (ppm)	1968	3.0	2.2	2.3	2.2	2.8	3.5
	1969	3.5	2.8	4.2	4.7	8.2	5.3
	1970	3.5	7.5	7.5	12.9	12.2	8.1
	1971	2.8	15.9	6.1	19.5	16.2	14.7
	1972	3.3	12.7	8.1	16.4	23.4	14.5
	1973	3.3	17.3	16.6	20.5	34.6	22.7
	1974	2.0	17.3	25.4	22.7	57.7	25.8
	1975	2.6	21.0	33.9	25.7	52.2	30.8
Sodium (ppm)	1973	3.9	4.6	7.8	5.5	6.7	6.2
	1974	2.2	3.1	5.0	3.6	5.8	5.9
	1975	2.0	2.9	4.4	3.3	5.3	5.7
Potassium (ppm)	1970	4.0	7.4	5.3	7.0	6.2	4.9
	1971	2.1	4.2	2.9	4.4	3.7	3.3
	1972	2.4	4.1	3.7	4.5	4.5	3.6
	1973	2.8	4.1	4.9	4.4	4.6	4.3
	1974	1.8	3.8	5.7	4.1	5.1	3.4
	1975	1.5	4.0	5.1	3.2	4.0	3.0
Iron (ppm)	1968	.12	.11	.38	.26	.25	.68
	1969	.15	.17	.78	.46	.35	.18
	1970	.11	.67	.86	.36	.29	.12
	1971	.21	.39	.76	.27	.25	.21
	1972	.02	.16	.44	.08	.05	.01
	1973	.06	.10	.10	.01	.00	.01
	1974	.05	.11	.06	.02	.04	.01
	1975	.07	.04	.04	.03	.02	.02
Aluminum (ppm)	1968	.02	.01	.02	.21	.02	.03
	1969	.03	.03	.04	.44	.04	.03
	1970	.06	.08	.08	.06	.06	.05
	1971	.03	.04	.04	.04	.04	.03
	1972	.02	.03	.03	.03	.03	.02
	1973	.02	.02	.02	.02	.02	.02
	1974	.02	.01	.00	.02	.01	.01
	1975	.03	.03	.02	.01	.00	.00
Manganese (ppm)	1968	.01	.01	.05	.07	.10	.00
	1969	.00	.01	.06	.55	.34	.01
	1970	.01	.29	.26	1.03	.21	.02
	1971	.01	.17	.08	.74	.27	.00
	1972	.00	.42	.23	.49	.46	.13
	1973	.01	.44	.56	.43	.29	.11
	1974	.00	.26	.37	.26	.25	.13
	1975	.00	.16	.38	.18	.12	.12
Zinc (ppm)	1975	.01	.01	.01	.00	.01	.01

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[a] The pH averages shown here were computed from the mean hydrogen ion concentrations that had been calculated from the measured pH values.

Figure 2.—Stream discharge and major dissolved ions, Jenny Fork watershed, 1968-1975 water years.

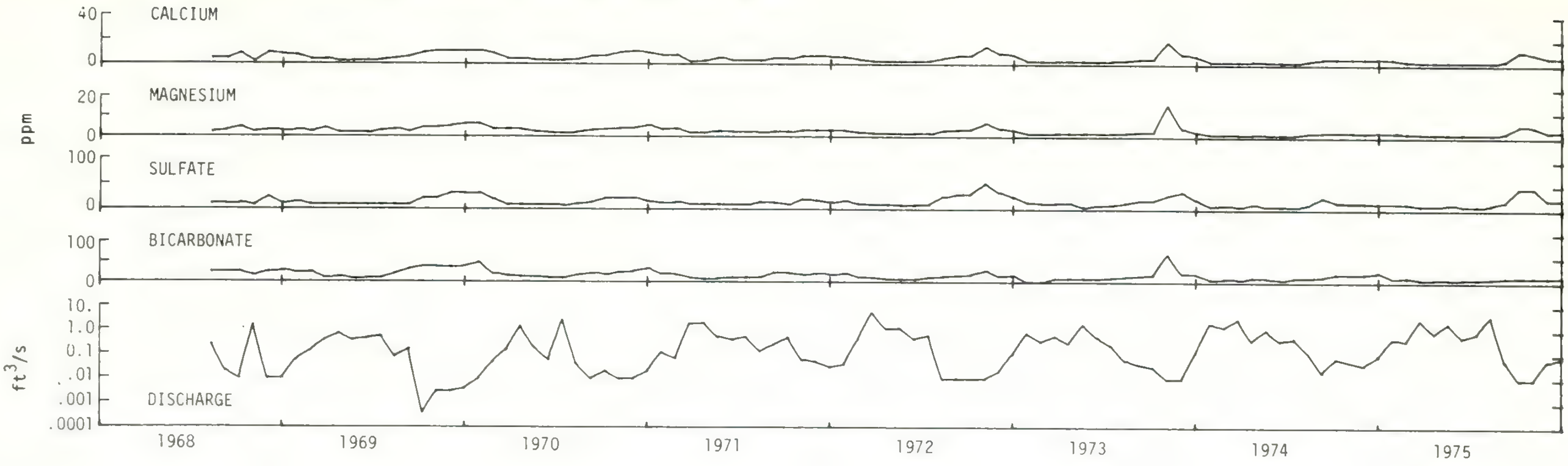


Figure 3.—Stream discharge and major dissolved ions, Miller Branch watershed, 1968-1975 water years. (shaded zones indicate periods of active mining)

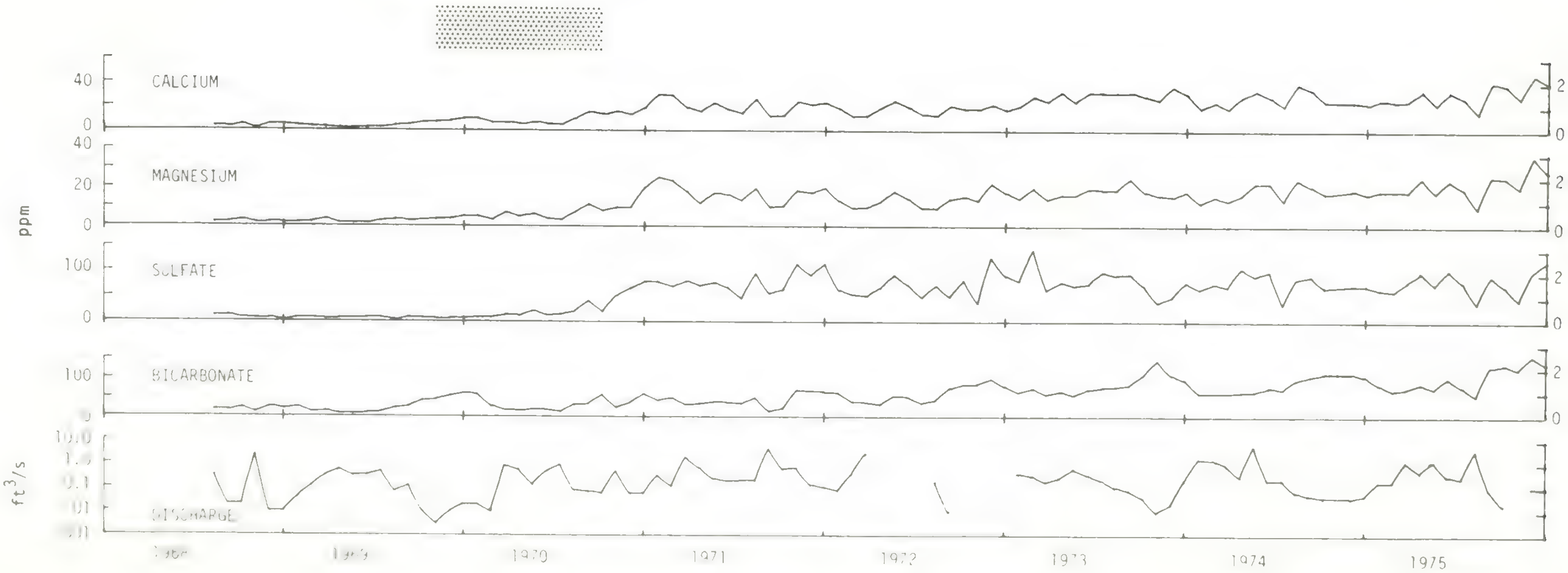


Figure 4.—Stream discharge and major dissolved ions, Mullins Fork watershed, 1968-1975 water years. (shaded zones indicate periods of active mining)

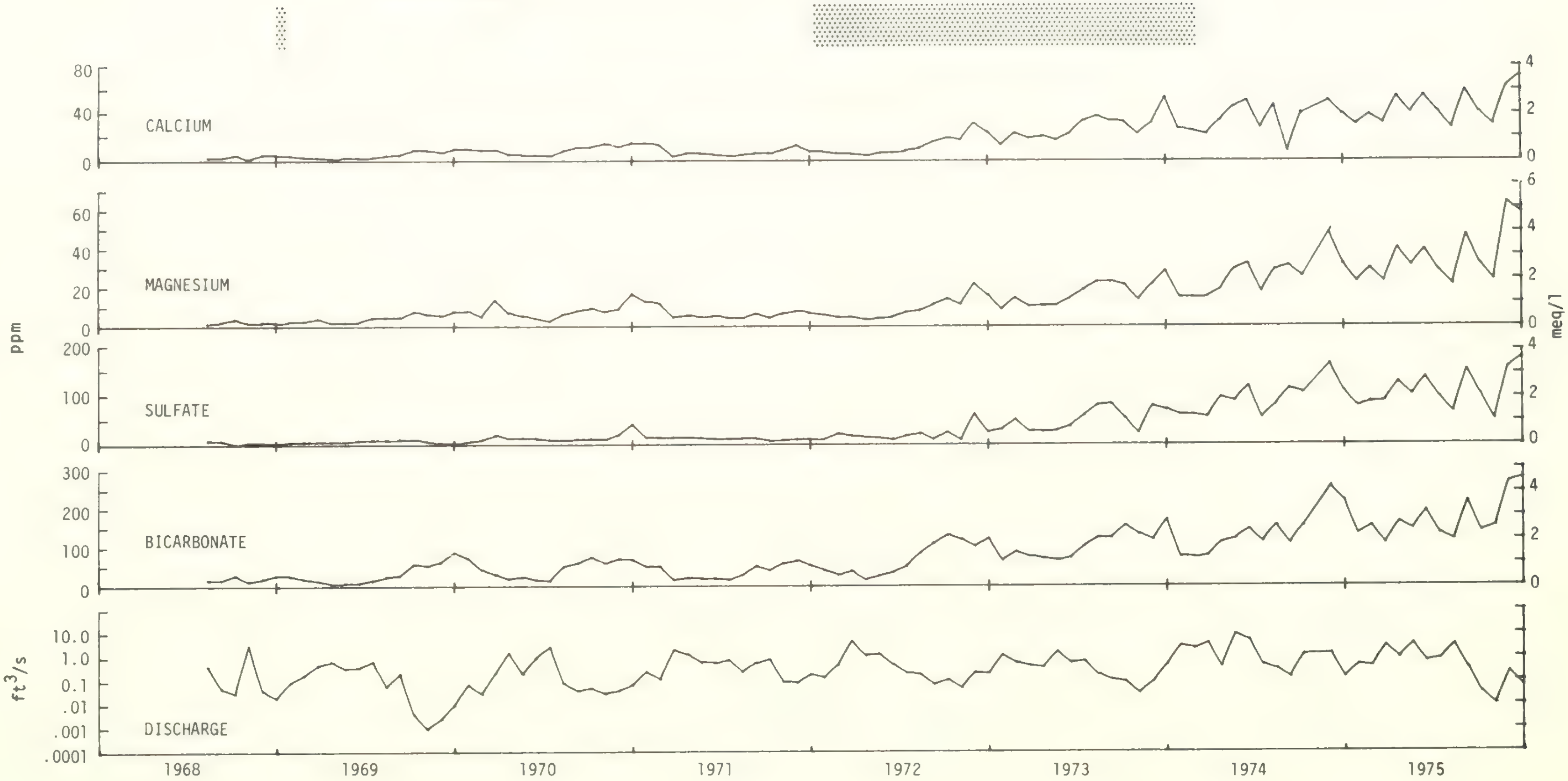


Figure 5.—Stream discharge and major dissolved ions, Leatherwood A watershed, 1968-1975 water years. (shaded zones indicate periods of active mining)

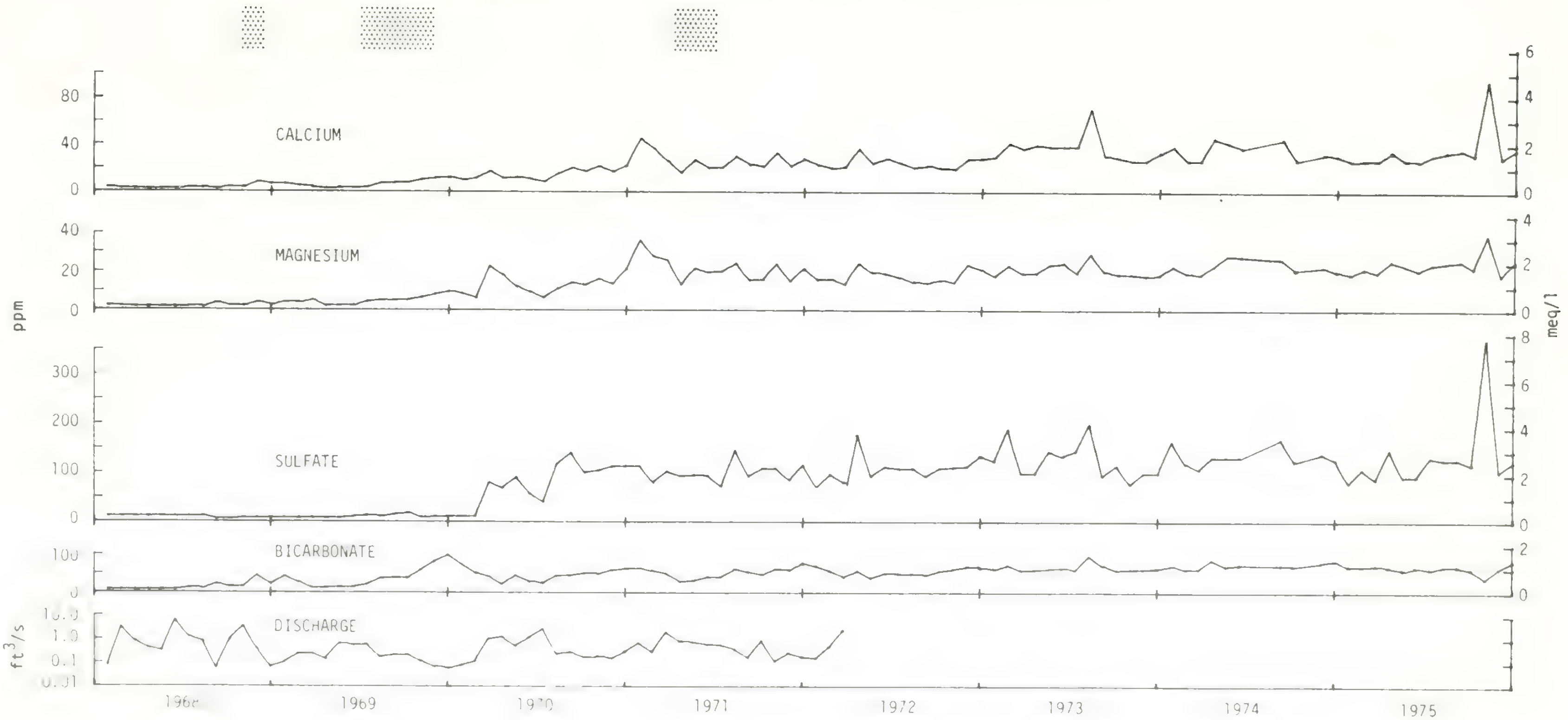


Figure 6.—Stream discharge and major dissolved ions, Leatherwood B watershed, 1968-1975 water years. (shaded zones indicate periods of active mining)

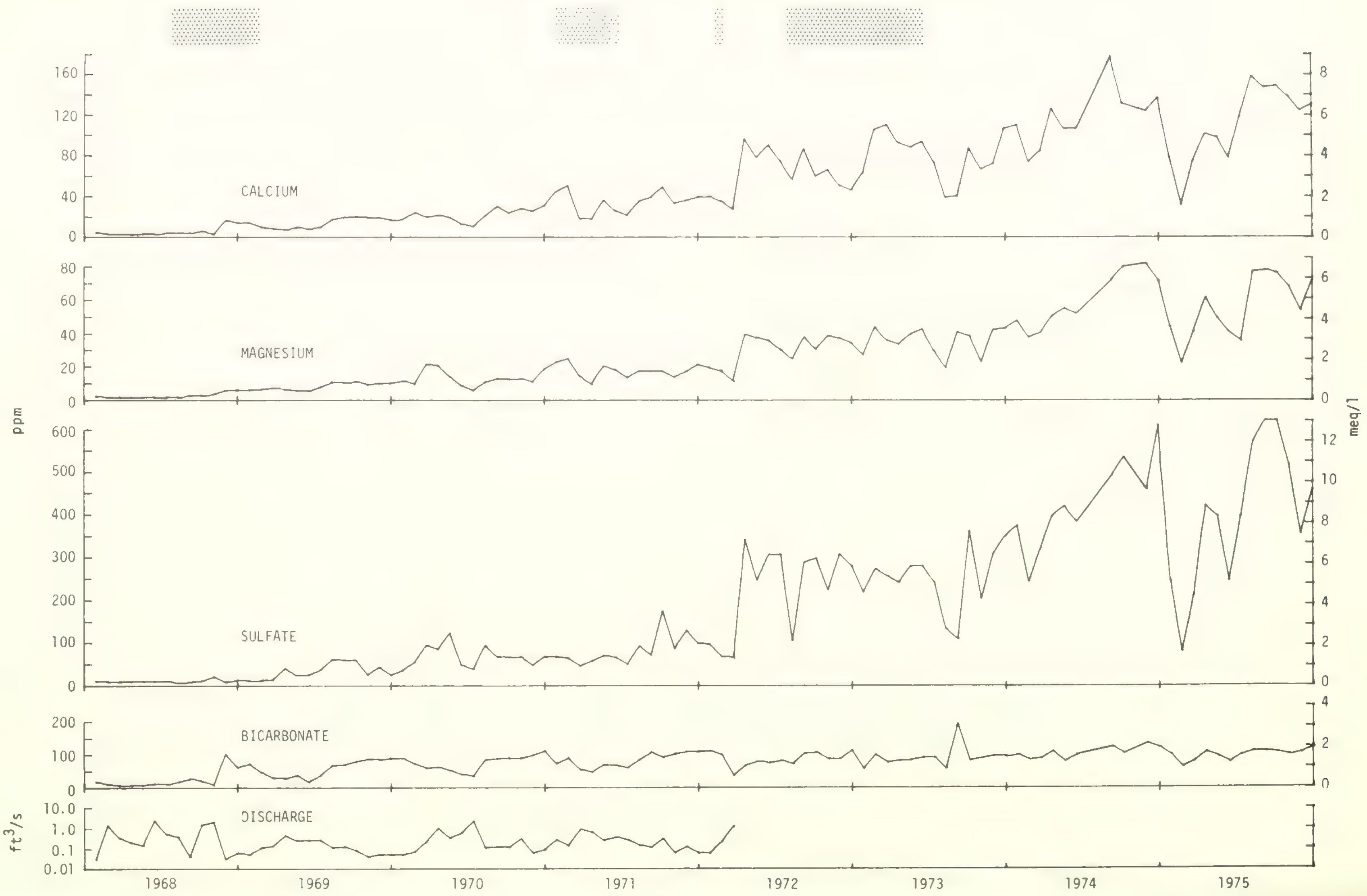
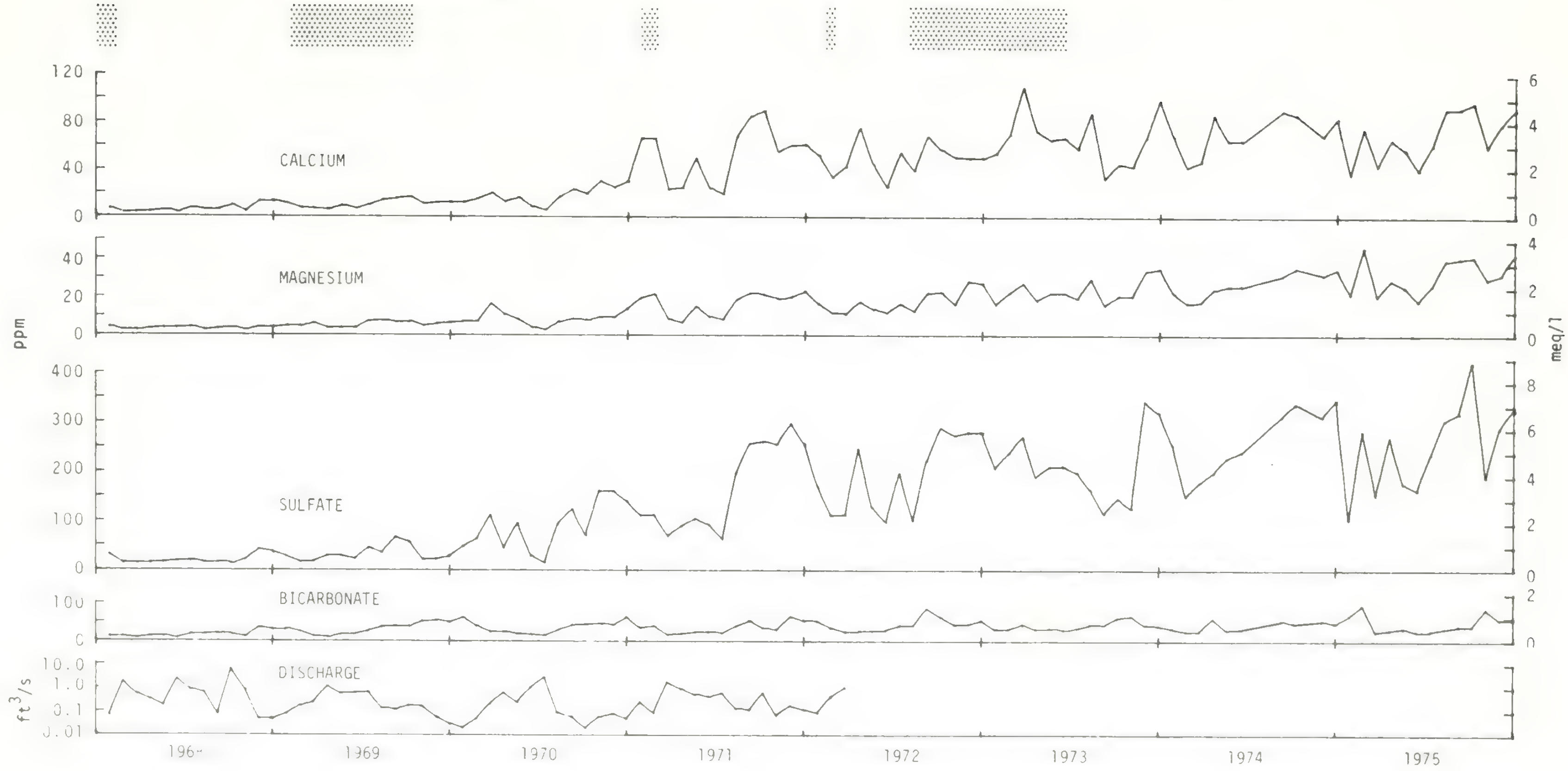


Figure 7.—Stream discharge and major dissolved ions, Leatherwood C watershed, 1968-1975 water years. (shaded zones indicate periods of active mining)



rise quickly in response to precipitation or snowmelt sufficient to cause runoff. The concentrations of most chemical constituents change almost as quickly in response to runoff events, but the changes in concentrations are of a lesser magnitude than are the changes in runoff. It is apparent from figures 2 through 7 that the concentrations of these four major constituents show approximately inverse relationships to the log of the discharge.

Salt loads were not calculated for inclusion in this paper, but in the cumulative data it is apparent that the highest total daily loads of dissolved constituents occurred during periods of high flow, when concentrations of these constituents were at or near their minimum levels.

pH AND ACIDITY

The summary of data in table 2 indicates that strip mining in the study area consistently caused an increase in the pH of stream water. In the 1973 through 1975 water years, Jenny Fork was slightly acid, with an average pH of 6.8, whereas the five mined watersheds were all slightly alkaline, with an average pH of 7.4. The maximum pH observed was 8.3 on 28 September 1975 in Mullins Branch; the minimum observed was 5.4 on 7 October 1968 in Leatherwood C. Both extremes occurred during low flow, 0.22 and 0.16 ft³/s respectively.

Acid water is a common problem in mined areas. It develops as a byproduct of the oxidation of pyrite (ferrous sulfide) through the following overall reaction.

$$FeS_2(\text{solid}) + 3\tfrac{3}{4}O_2 + 3\tfrac{1}{2}H_2O \rightarrow 4H^+ + 2SO_4^= + Fe(OH)_3(\text{solid}) \quad [1]$$

Although large quantities of acid are produced in the mined portions of Leatherwood Creek and Bear Branch, it is quickly neutralized, apparently before it leaves the spoil material and before it enters the streams. This is common throughout much of Appalachia. Part of this neutralization occurs when acid ground water contacts carbonate minerals we know to be present in the overburden on the Bear Branch and Leatherwood Creek watersheds. Additional neutralization probably occurs when the hydrogen ion (acid) from the water replaces the exchangeable bases (calcium, magnesium, sodium, potassium, etc.) from the soils, spoils, and aquifer materials that it contacts.

SULFATE

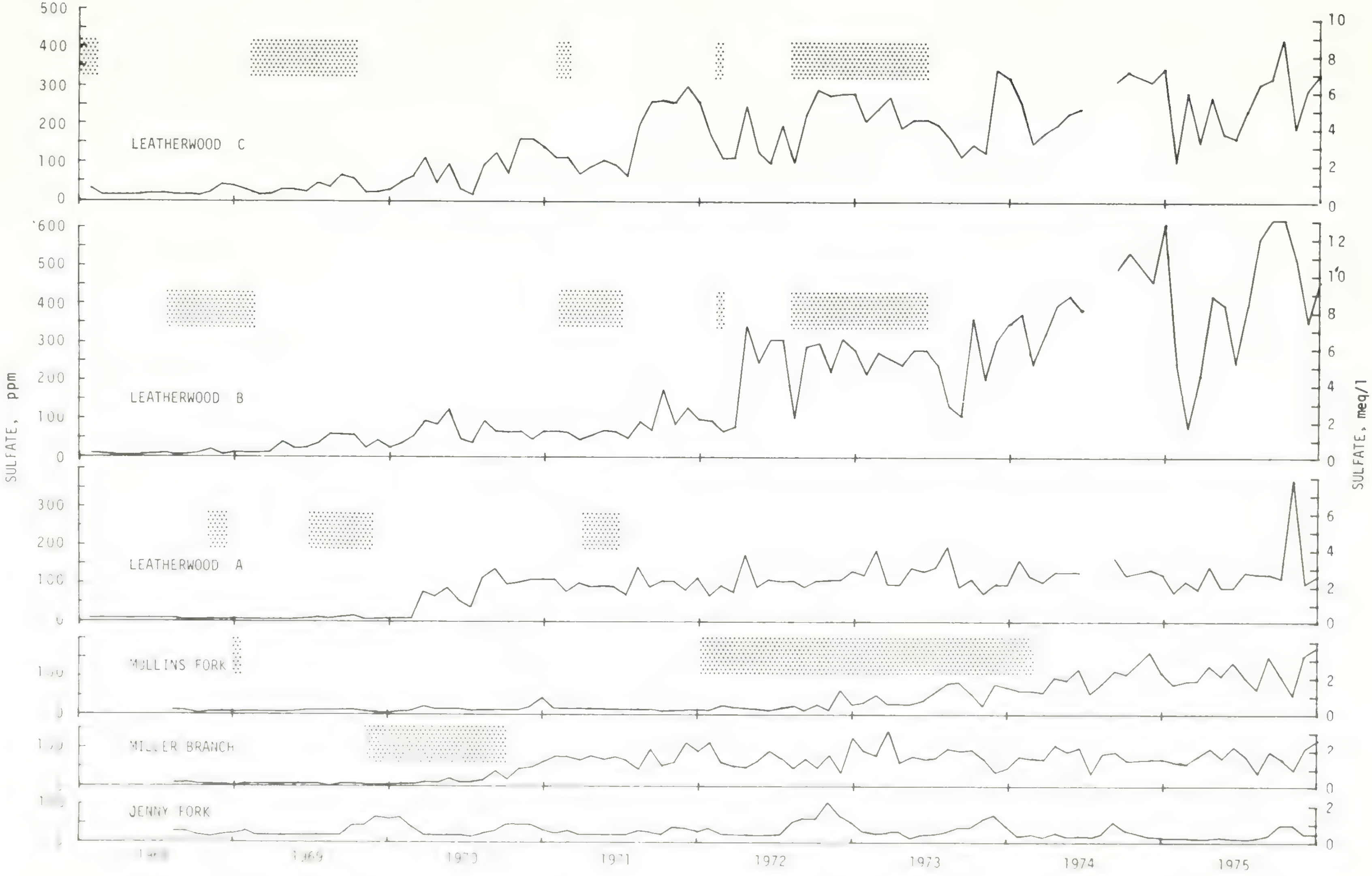
In the six small streams under investigation, sulfates show the greatest, though perhaps not the most immediate, response to mining and other earth-moving activities. Data from all six watersheds are graphically compared in figure 8. Before mining, the mean concentration of sulfates in these streams was generally less than 15 parts per million (ppm), but after mining the concentrations were generally in excess of 100 ppm. The sulfates observed in Jenny Fork and in the other streams before mining were contributed jointly by precipitation, dry atmospheric fallout, and natural geologic weathering processes. Aside from the small quantities of sulfates from the precipitation and atmospheric fallout, essentially all the sulfates observed in Appalachian streams originate from the dissolution of pyrite through the process described in equation 1.

As figure 8 shows, sulfate concentrations continue to increase after mining has ceased, sometimes for as long as 2 years. There are at least three reasons for this delay: (1) A certain amount of time is required for pyrite to oxidize once it has been exposed to the atmosphere and water; but once the reaction is underway, it should proceed at a fairly constant rate except for small seasonal variations caused by temperature differences. (2) Time is required for ground water to transport sulfates from the mine spoils to the streams. (3) Anion exchange with other anions in soil, spoil, and aquifer materials will delay transport of sulfate relative to movement of the water *(Thomas 1960; Yaalon 1964)*.

The continued presence of high levels of sulfate may possibly be explained by the following: If the initial oxidation of pyrite is extremely rapid, gypsum may precipitate from solution in the spoil banks, then redissolve when the oxidation of pyrite slows to the point at which the drainage water is no longer saturated with gypsum. This process allows a fairly steady level of sulfate to be maintained in the drainage waters from the time of mining until the gypsum has all dissolved.

Sulfate concentrations reached a maximum of 625 ppm in Leatherwood B, the most heavily

Figure 8.—Comparison of dissolved sulfate concentrations in six streams, 1968-1975 water years (shaded zones indicate periods of active mining).



mined watershed. Although this is more than twice the suggested maximum concentration (250 ppm) of sulfate in drinking water for humans *(U.S. Public Health Service 1962, p. 7)*, it is considered satisfactory for livestock or aquatic life *(McKee and Wolf 1963)*.

CHLORIDES

Chloride data were collected only for the 1973 through 1975 water years. From table 2, it is apparent that the chloride concentrations were very low in all six streams. Strip mining caused an increase in chloride concentration of approximately 1 ppm or less, a negligible increase.

BICARBONATES

The concentration of bicarbonates in stream water samples increased immediately after mining, approximately in proportion to the percentage of disturbed land on the watershed. Mullins Fork was exceptional in that, with a relatively small percentage of the land disturbed (41 percent), it still produced by far the largest concentrations of bicarbonate ion. The reason for this is not known, but it may be that a stratum of limestone or dolomite was uncovered in the Mullins Fork watershed that did not extend to the others, or there may have been a different arrangement of strata in the spoil material. Abnormally high concentrations of bicarbonate ion in stream water were sometimes noted immediately prior to mining on the watershed; these may have been due to natural variability or caused by road building or other, relatively minor, earth-moving activities.

CARBONATES

Carbonates were not detected in any stream water samples before or after mining. Unless the pH of the sample exceeds 8.3, measurable quantities of carbonate will not be present; in no case did the pH of the sample exceed 8.3.

CALCIUM AND MANGNESIUM

Calcium and magnesium together account for more than 90 percent of the dissolved cations (on a chemical equivalent basis) in waters from mined watersheds, but for only 70 percent of those in waters from unmined watersheds. Measured in terms of chemical equivalents, the concentrations of calcium and magnesium are roughly equal in the study watersheds, each being greater in some cases. The concentrations of both ions increase in response to strip-mining activities; much of this response is immediate, but some of it may be delayed for 2 years or longer. The immediate response is associated largely with the increase in bicarbonate concentration, whereas the delayed response accompanies an increase in sulfate concentration.

SODIUM AND POTASSIUM

Sodium and potassium together account for about 30 percent of the dissolved cations (on a chemical equivalent basis) in waters from unmined watersheds, but for only 10 percent or less of those in waters from mined watersheds. The concentrations of both ions in stream samples from mined watersheds are about twice those in samples from unmined watersheds; even so, this concentration does not significantly degrade the quality of the water.

IRON, ALUMINUM, MAGANESE, AND ZINC

All four cations are dissolved in low concentrations in stream water samples from both mined and unmined watersheds. With the possible exception of zinc, all seem to increase somewhat in concentration during and immediately after mining, then return to normal within about 1 year after cessation of mining. From 1968 through 1975 annual zinc concentrations averaged less than 1 ppm on all watersheds. Only the 1975 data are reported in table 2 because the atomic absorption unit used before that time is known to have erred on the high side in zinc determinations, probably because of an additive interference from other ions.

DISCUSSION

Rate of recovery

Once mining and other earth-moving disturbances have ceased on a watershed, the quality of water in the streams will gradually return to normal. For water chemistry, this is proving to be a very slow recovery in the watersheds under study. At the end of the 1975 water year, the Leatherwood A watershed had not been mined in more than 4-1/2 years and the Miller Branch watershed had not been mined in almost 5-1/2 years, yet it is apparent from figures 3 and 5 and table 2 that very little recovery had taken place. Other researchers have found faster recoveries in other mined areas. For example, Collier and others (*1970*, p. C21-C30) observed a quick decline in sulfate and dissolved solids loads in Cane Branch (McCreary County, Kentucky) in the first 1 or 2 years after strip mining had ceased, but found little additional recovery during the next 5 years.

Time of travel of dissolved constituents

The data in figures 3 through 8 show a lag of 6 to 12 months or longer between mining activity and a full response in stream-water chemistry to the mining.

Two of the reasons for this lag are (1) the time required for the oxidation and solution of pyritic minerals, and (2) the time required for transport of the dissolved spoil minerals. Nearly all the dissolved solids originating in the mine spoils of the watersheds under study must travel at length through soil and/or aquifer materials before they enter a stream. Gang and Langmuir (*1974*, p. 54) demonstrated that the major pollution sources on certain Pennsylvania streams were shallow ground-water discharges that drained mine spoils. There is every reason to believe that this is also true in the Leatherwood Creek and Bear Branch watersheds. It is during the period of travel as ground water that the acids produced by oxidation of pyritic materials are either neutralized by contract with limestone or other calcareous materials or else are replaced by exchangeable bases associated with spoil, soil, or aquifer materials.

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- Warren, Pennsylvania.

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1977. **Effect of strip mining on water quality in small streams in eastern Kentucky, 1967-1975.** NE. For. Exp. Stn., Upper Darby, Pa.
13 p., illus. (USDA For. Serv. Res. Pap. NE-372)

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Keywords: Strip mines, Appalachian mountain region, streams, water quality, weathering, water chemistry

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by Benjamin A. Roach

A Stocking Guide for Allegheny Hardwoods and Its Use in Controlling Intermediate Cuttings

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THE AUTHOR

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ABSTRACT

A stocking guide for stands of Allegheny hardwoods (sugar maple or sugar maple-beech with varying admixtures of black cherry, red maple, white ash, sweet birch, and other species) on the Allegheny Plateau in northwestern Pennsylvania. Included are procedures for evaluating stocking and stand conditions, thinning even-aged stands, determining minimum residual stocking, distributing the basal-area cut in a stand, and using the guide for selection cutting.

A Stocking Guide for Allegheny Hardwoods and Its Use in Controlling Intermediate Cuttings

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- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
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- Warren, Pennsylvania.

INTRODUCTION

CONTROL OF STAND DENSITY is the principal means that foresters have for regulating stand growth. Ideally, to grow a full crop of wood products as quickly as possible, we should always have in our stand the minimum number of trees that will just use all of the light, moisture, and nutrients that are available on the site each growing season. The problems have always been how to define this ideal, and then how to achieve it.

Through the years many stocking guides have been developed to aid the forester in judging how well his stand is stocked compared to some prescribed standard, and, consequently, how the stocking would have to be changed to approach the ideal. In my opinion the best of the modern guides is the one developed by Gingrich *(1967)* for the oaks. It describes the maximum stocking to be expected and the minimum stocking that is needed for full yield, in basal area per acre, for a stand of a given average diameter. The guide has a rational biological basis; it is generally independent of the influence of site, age, or stand structure; and the measurements that are needed for its application can be easily and quickly obtained in the field. Similar guides have since been developed for use in the Northeast: northern hardwoods *(Leak, Solomon, and Filip 1969);* paper birch *(Marquis, Solomon, and Bjorkbom 1969);* spruce-fir *(Frank and Bjorkbom 1973);* and white pine *(Philbrook, Barrett, and Leak 1972).*

Following Gingrich's lead I have developed stocking guides for stands of Allegheny hardwoods (sugar maple or sugar maple-beech with varying admixtures of black cherry, red maple, white ash, sweet birch, and other species) on the Allegheny Plateau in northwestern Pennsylvania. This guide differs from the others listed in that I found it necessary to incorporate a measure of stand composition—specifically, the basal area in black cherry, white ash, and yellow-poplar expressed as a percentage of the total basal area of the stand.

BACKGROUND

The growth rate of a healthy tree is determined largely by the amounts of light, moisture, and nutrients that are available to it year after year. If these elements are continuously available in amounts equal to the tree's ability to use them, the growth rate of the tree should be at a maximum. If their availability becomes less than optimum, the growth rate of the tree is reduced; if their availability is reduced too greatly the tree will die.

The larger the tree, the greater are the amounts of light, moisture, and nutrients required for its survival and growth. But (if we ignore variables such as fertilization, irrigation, and climatic variation) the total amounts of these elements that are available on a site can be considered constant year after year. So as the trees increase in number or in size, undisturbed stands tend to reach and maintain a maximum degree of crowding. As some trees grow, others must die. The surviving trees receive less than optimum amounts of light, moisture, or nutrients, and their growth is relatively slow.

The area of a given site is, of course, constant. And if the amounts of light, moisture, and nutrients that reach the site can also be considered constant, they may be thought of collectively as the growing space available. This growing space can be expressed in area, and the area can be allocated mathematically among the trees present according to size. The tree-area ratio *(Chisman and Schumacher 1940)* is useful for this purpose.

TREE-AREA RATIO FOR ALLEGHENY HARDWOODS

I collected data on 106 natural hardwood stands throughout Warren, McKean, Forest, and Elk Counties in Pennsylvania. Some data came from measurements of temporary plots; other data were gleaned from research records dating as far back as 1928.[1]

The criteria for selecting the stands were somewhat subjective. Primarily there had to be no reason to believe that the stand was not at the maximum degree of crowding permitted by the site; that is, the stands had to show no evidence (on direct examination or in the records) of past cutting or other disturbance. The only exceptions were six research plots on which there had been a very light cutting more than 30 years earlier. However, no stands were excluded just because they seemed to have fewer trees or less basal area than others, if there was no evidence of disturbance. Because the tree-area ratio seems to be generally independent of site quality, I made no attempt to determine site quality.

The stand data consisted of tables of numbers of trees per acre that were 1.0 inch in diameter at breast height (dbh) or larger, by species and 1-inch diameter class; the data were compiled from diameter tape measurements of every tree on the plot. The plots ranged in size from 1/4 acre to 20 acres, and totaled 175 acres with about 125,000 trees. Stand age ranged from 18 to more than 100 years; basal area ranged from 60 to 175 square feet per acre, and number of trees from 200 to 5,000 per acre. From these tables I calculated the number of trees per acre, the sums of the diameters per acre, and the sums of the squared diameters per acre, by species for each plot.

These data were used to solve the tree-area equation:

$$\text{Tree area} = (a_1N_1 + b_1\,\Sigma D_1 + c_1\,\Sigma D^2{}_1) + (a_2N_2 + b_2\,\Sigma D_2 + c_2\,\Sigma D^2{}_2)\ \ldots$$

where a, b, and c are regression coefficients.

The subscript numbers indicate different species or species groups.

N is the number of trees.

ΣD is the sum of diameters.

ΣD^2 is the sum of squares of the diameters.

If all figures are calculated on a per-acre basis, *then* tree area should be 1 acre or 1,000 milacres.

The best regression (highest R^2 and lowest standard error of the estimate) was based on six species groups: sugar maple/beech/black cherry-white ash-yellow-poplar/red maple/yellow birch-sweet birch/miscellaneous. The miscellaneous group consisted of pin cherry, hemlock, basswood, aspen, cucumber-tree, striped maple, American hornbeam, hophornbeam, and serviceberry. Except for pin cherry in young stands, trees of the miscellaneous group occurred as scattered individuals.

The equation is: Tree area (milacres) = $-18.4188 -.1754\,\text{Nsm} + .1953\,\Sigma\text{Dsm} + .0353\,\Sigma\text{D}^2\text{sm} + .2537\,\text{Nbe} -.1256\,\Sigma\text{Dbe} + .0628\,\Sigma\text{D}^2\text{be} + .4172\,\text{Nbc-wa-yp} + .1690\,\Sigma\text{Dbc-wa-yp} + .0075\,\Sigma\text{D}^2\text{bc-wa-yp} - .4342\,\text{Nrm} + .2726\,\Sigma\text{Drm} + .0162\,\Sigma\text{D}^2\text{rm} + .8288\,\text{Nbir} - .2012\,\Sigma\text{Dbir} + .0630\,\Sigma\text{D}^2\text{bir} - .2878\,\text{Nmisc.} + .2263\,\Sigma\text{Dmisc.} + .0017\,\Sigma\text{D}^2\text{misc.}$

This regression is highly significant with a coefficient of multiple determination (R^2) of 99.6 percent. The standard error of estimate is 43.8 milacres or about 5 percent of the mean tree area of the plots.

SO WHAT?

From the high R^2 and small standard error, we can be reasonably confident that undisturbed stands of Allegheny hardwoods do indeed achieve an average maximum degree of stocking, and that we can describe this average maximum mathematically. By plugging into the equation the appropriate per-acre measurements for any stand, we can determine the number of milacres that the stand occupies when each tree is allocated the average minimum growing space that it needs to survive. If we divide that figure by 10, we will obtain the stocking percentage in the stand compared to the average maximum stocking (100 percent) for an undisturbed natural stand of the same composition and average diameter.

---

[1] I thank personnel of the Pennsylvania Bureau of Forestry and of the School of Forest Resources of The Pennsylvania State University for the use of stand data that they generously made available for this study.

Unfortunately, this stocking equation is not very useful for determining relative stocking in the woods. The number of trees can be obtained easily by counting them on sample plots. The sum of the squared diameters can be obtained easily by conversion from basal-area estimates; the latter can be made quickly with a wedge prism.[2] But the sum of diameters term requires a measure, or at least an estimate, of the diameter of many individual trees, and this takes much time and computation. Therefore, it would be convenient if a reasonably accurate estimate of stocking could be obtained without using the sum of diameters term.

The sum of diameters is useful primarily for indicating the differences in stocking between stands that have the same basal area and number of trees, but different structures. Gingrich *(1967)* found that differences in structure among oak stands resulted primarily from differences in species composition. But, with the exception of yellow-poplar, the species usually encountered in oak stands all had about the same requirements for growing space. That is, a 12-inch white oak required about the same amount of growing space as a 12-inch black oak or a 12-inch hickory. Therefore, if the amount of yellow-poplar in an oak stand were relatively low, both structure and composition could be ignored. Stocking estimates could be based on only the number of trees and basal area per acre.

This is because the number of trees per acre and the basal area per acre, taken together, mathematically define the diameter of the tree of average basal area (hereafter referred to as the average stand diameter). As nearly every normal yield table will show, there is a close relationship between the average stand diameter and the maximum basal area per acre. Therefore there must be an equally close relationship between the maximum basal area per acre and the number of trees per acre. So, for any forest type with a particular typical structure (so that the sum of diameters term becomes insignificant), a regression of maximum basal area per acre on number of trees per acre provides a means for displaying graphically the tree-area equation for average maximum stocking in that type. If we superimpose on that graph the lines that indicate the average stand diameter, we can see the relationship between average stand diameter and maximum basal area.

Then it becomes a simple matter to determine the relative stocking of any stand, if its average diameter is known, by comparing the basal area of the stand with the basal area shown on the chart for a stand of the same average diameter. Also it is easy to determine the residual basal area that is needed for any degree of stocking, as long as cutting does not cause a significant change in stand structure. Finally, the degree of stocking and the average stand diameter should provide an excellent basis for predicting future growth and development—both for individual trees and for stands—once the necessary data are accumulated.

Although the structure of Allegheny hardwood stands varies much more than that of oak stands, I had hoped that a stocking guide based only on number of trees and basal area might be accurate enough for field use, but this hope proved illusory. The regression of basal area on number of trees per acre, though highly significant, had an R^2 of only 34 percent, and a standard error of the estimate of 16 percent. It seemed logical that the low R^2 and the high standard error were due to large variations in structure among the sample stands. Obviously, some measure of structure had to be included.

I couldn't think of any indicator of structure that promised reasonable accuracy and that would be any easier to obtain than the sum of diameters. But it seemed likely that the variation in structure was caused primarily by two factors: differences in stand age, and the wide range in species composition.

There was a modest improvement in results after I incorporated stand age in the regression of basal area on number of trees per acre, but it was considerably less than I had expected. So I investigated a number of possible indicators of composition.

The best indicator that I found was the percentage of basal area in the stand that was contributed by each species. In fact, when this variable was included the effect of stand age disappeared. This indicator was convenient because it promised to eliminate the practical difficulties of determining stand age in the field, or trying to assign a specific age to stands containing more than one age class. And by tallying number of trees and basal area by six species groups, I found that relative stocking could be estimated with the same accuracy as it could with the complete tree-area equation.

---

[2] Because basal area and the sum of squared diameters are essentially the same, it makes sense to use basal area directly rather than perform a needless conversion to sum of squared diameters.

But trouble developed when I tried to use this method in the woods. I found that I would have to carry a large number of charts to cover the many possible species combinations, or carry one of the more sophisticated pocket calculators to solve the complex equation for each combination. Also, this method required a detailed marking inventory and complicated calculations to determine residual stocking. In short, the method was accurate, but too unwieldy; I found that two species groups were the most I could handle without difficulty.

So I tried many combinations to find the two species groups that gave results that were the most consistent with the full tree-area equation; these two groups proved to be one containing black cherry, white ash, and yellow-poplar, and another containing all other species.

STOCKING GUIDE FOR ALLEGHENY HARDWOODS

The overall stocking regression for Allegheny hardwoods produced the following equation (for 106 plots):

> Basal area per acre for 100 percent stocking = 272.5248 - 59.7549 (Log_{10} of number of trees per acre) + 0.7032 (percentage of total basal area in the stand contributed by black cherry, white ash, and yellow-poplar).[3]

This regression has a coefficient of determination (R^2) of 67.4 percent, and a standard error of estimate of 13.77 square feet of basal area, or about 11 percent of the mean basal area of the plots. This standard error is a little more than twice that for the tree-area equation. I believe that most of the additional error resulted because the differences in stand structure and composition cannot be accounted for adequately when only two species groups are used.

Although the degree of accuracy of this regression may be adequate for field use, or at least better than guessing, it seemed desirable to improve it if possible. Also stocking percentages that were calculated for individual stands with this equation differed considerably from the stocking percentages calculated from the tree-area equation at the extremes of diameter and composition.

So I stratified the data by using the percentage composition and calculated new regressions for each 10-percent change in composition from 0 to 40 percent; I used an additional regression for curves from 50 to 80 percent. These new regressions made an excellent progression, and none crossed any other within the range of the data. The R^2 (coefficient of multiple determination) of these regressions is 70 percent; the standard error of the estimate is 10.5 percent. I accepted the 0- and 80-percent curves as the extremes, and the original regression (average composition of 40 percent) as the mean, and distributed the curves of 10, 20, 30, 50, 60, and 70 percent progressively throughout the range. Figures 1A and 1B are versions of this chart that have been condensed for easier use in the field.

As the chart shows, when a fully stocked stand grows older, overcrowding causes mortality (mostly among the smaller trees) and reduces the number of trees per acre. This, combined with continued growth of the remaining trees, increases the average stand diameter. Because larger trees use growing space more efficiently than smaller trees, the total basal area of the stand continues to increase toward the maximum that the site can carry. This maximum depends on the sizes of the trees in the stand, which are reflected by the average stand diameter.

The A-level curves on figure 1 show the average maximum basal areas per acre that will be attained by undisturbed Allegheny hardwood stands with given average diameters when various percentages of the basal areas are contained in black cherry, white ash, and yellow-poplar. If the percentage composition does not change, successive plots of the basal area-number of trees relationship for a heavily stocked stand should fall progressively to the left along the appropriate A-level curve on the chart. Usually, though, the cherry-ash-poplar group grows faster than the birch-beech-sugar maple component, so the percentage composition tends to increase; and the stand tends to be represented by a higher curve.

---

[3] In exploring the shape of the regression curve of basal area per acre on number of trees per acre, I found that three transformations gave better correlations than the straight line: Log X, Log Y, and the quadratic. The quadratic gave the best correlation (by a very small amount) within the range of the data; however, when the curves were extrapolated beyond the limits of the data, the quadratic and Log Y forms produced entirely unrealistic estimates (as, of course, does the straight line). The Log X estimates looked very reasonable so I used Log X (Log_{10} of number of trees per acre).

These curves should be thought of as averages. Many times the plot of a stand will fall somewhat above or below the appropriate curve, and the stand might still be considered perfectly "normal". One reason for this, of course, is the normal biological variation, and the statistical error that is inherent in the curves—the standard errors of the estimate are around 10 percent. Another reason is the variation in growing conditions from year to year. For example, if soil moisture in the summer is a limiting factor for growth, a period of wetter-than-average growing seasons will permit stocking to increase above the A level. Conversely, a period of drought years will increase mortality and cause the stand to drop below the A level. This became very apparent when I was examining stand records spanning the drought of the early 1930's. But whether it is currently above or below A level, the long term trend of the stand should be toward that level.

The B-level curves on figure 1 are not based on field data; they are my preliminary estimate (guess, really) of the minimum stocking that is needed for full utilization of the site.

Gingrich *(1967)* calculated a minimum stocking level for the oaks from crown measurements of open-grown trees. His B level is the stocking at which the sum of the cross-sectional areas of the oak crowns would just equal the ground surface area of the stand if each tree had its maximum crown size. His B-level basal areas range from 55 to 58 percent of the A levels. The B level that is recommended for northern hardwoods in New England ranges from about 54 to 69 percent of the A level *(Leak et al. 1969)*. In the United States generally, the recommended basal area to be left after thinning ranges from about 50 to 70 percent of the maximum that is encountered. For maximum wood production, European foresters recommend slightly higher "B levels", ranging from about 60 to 80 percent of maximum. The upper part of this range is recommended primarily for the more intolerant species (especially Scotch pine) or for stands in the latter part of relatively long (by U.S. standards) rotations *(Assmann 1970; Braathe 1957)*.

I have not made a study of crown diamters of Allegheny hardwood species, and growth studies are too recent to indicate the stocking level that produces the maximum net basal-area growth. From general observation I recommend 60 percent of A-level stocking as an estimated average B level that should be adequate until data are available from which to derive a better one. Thus the B levels (dashed curves) on the stocking chart (fig. 1) are calculated at 60 percent of the A levels for stands of the same average diameter.

THE STAND INVENTORY

Use of the stocking chart requires the following stand data: (1) the total basal area per acre; (2) the percentage of that basal area that is contributed by black cherry, white ash, and yellow-poplar (hereafter referred to as *percent CAPs)*; and (3) the *average stand diameter* (diameter of the tree of mean basal area). These can be determined from data that are required during a sample cruise of the stand.

The following procedure is not the only one that can be used, but of those that I investigated, this procedure was the simplest and most convenient one that still provided acceptable accuracy.

Planning the Sample Cruise

The first step is to determine the stand boundaries; they should be set primarily to keep the stand as uniform as possible in composition, age, site quality, and structure. But some consideration also should be given to ease of future management. If the boundaries coincide with easily recognized features of the terrain, field work will be more efficient, records will be more reliable, and there will be less danger that the stand boundaries will be "lost" in the administrative records of stand treatments. It is often impossible to satisfy both objectives, but a small compromise will often simplify administration without causing a great increase in variability.

The optimum size of the stand will vary with many factors, especially the size of the property, the objectives of the owner, the ease of access, the nature of markets, and the need to protect or improve other resources—for example, wildlife habitat. It will often prove convenient if the

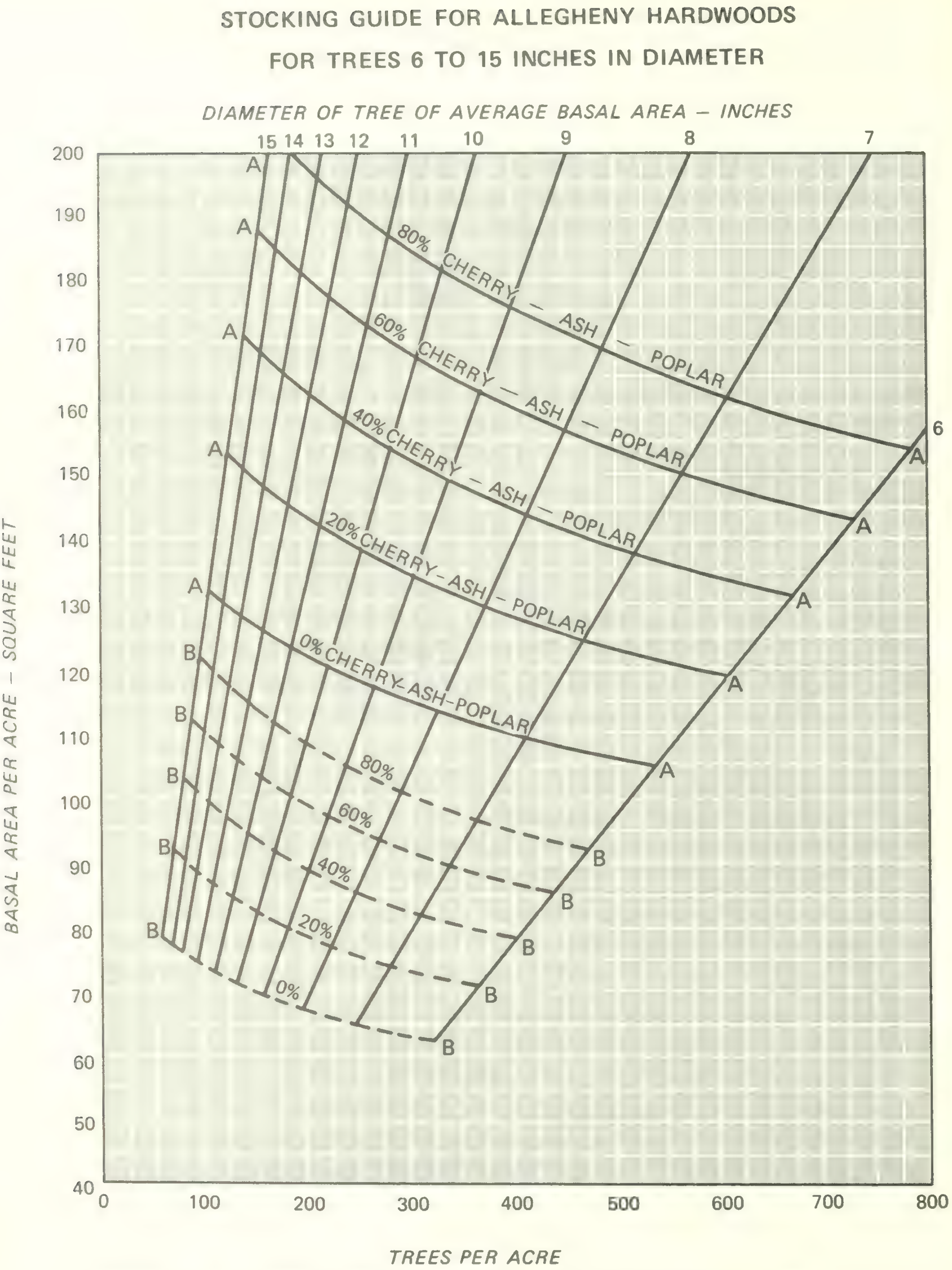


Figure 1A.—Stocking guide for Allegheny hardwoods, for trees 6 to 15 inches in diameter.

STOCKING GUIDE FOR ALLEGHENY HARDWOODS
FOR TREES 3 TO 10 INCHES IN DIAMETER

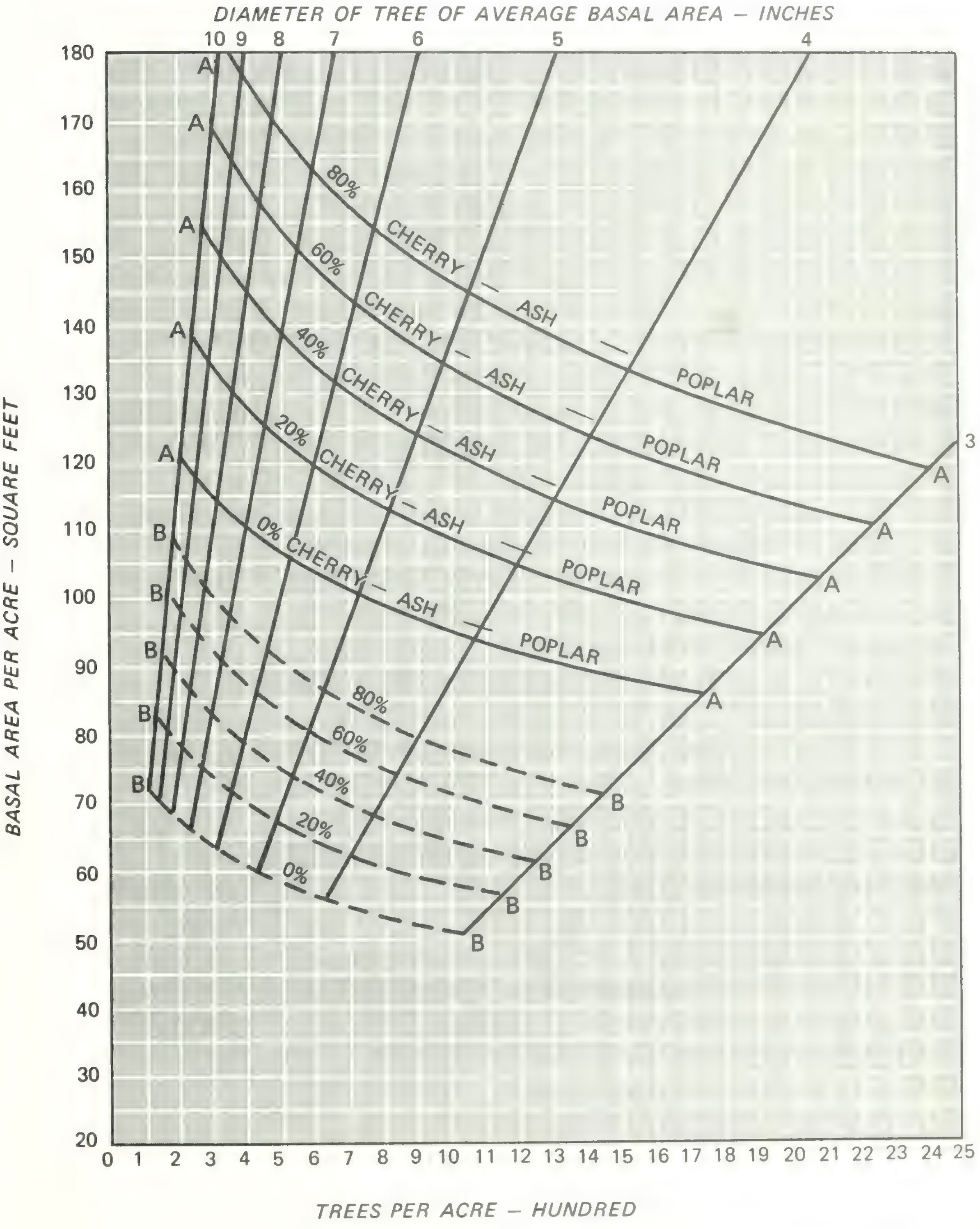


Figure 1B.—Stocking guide for Allegheny hardwoods, for trees 3 to 10 inches in diameter.

stand is large enough to provide a reasonably efficient field operation by itself, but not so large that variability is increased greatly. Generally I would not consider a stand that is smaller than 3 to 5 acres as a separate entity; and stands this small may be difficult to regenerate if there are many deer around. At the other extreme, I would rarely accept a stand as large as 50 acres.

The shape of the stand can also be an important factor when it is time to regenerate it. Deer seem to hit a long narrow stand harder than they hit a shorter, wider stand of equal area (unless the area is so small that the deer eliminate reproduction regardless of the stand's shape).

After the stand boundaries have been determined, the next step is to lay out a travel route for the sampling. Usually, several trips should be planned through the stand, and on parallel lines that are spaced several chains apart. Sample points should be spaced along the lines mechanically. Of course, the lines should be laid out to provide reasonable coverage of the whole stand, not just its most accessible areas.

The number of lines, the spacing between them, and the spacing between sample points must be set so that there are enough samples to provide accurate averages for the stand. Experience in previously unthinned 50-year-old stands indicates that 10 to 12 sample points are required to reduce the standard error of the mean basal area to 10 percent or less. Older stands, especially those that have been previously thinned, require more sample points.

I use 10 sample points as the absolute minimum for a stand, and then only if the stand is small (less than 15 acres) and if the basal area and structure are nearly uniform from point to point. In stands that are larger than 15 acres, I usually shoot for one sample point per 1 1/2 to 2 1/2 acres, and plan on a maximum of 20 points.

The Basal-Area Tally

At each sample point a wedge prism is used to obtain a dot tally of basal area per acre (trees 1.0 inch in dbh or larger), by two species groups (CAPs and other) and by four major size classes (saplings, poles, small and large sawtimber). When the sample cruise is completed the dot count is totaled and converted to a per-acre basis (fig. 2A).

It is necessary to tally the basal area by the two species groups to determine the percentage composition: basal area in CAPs divided by total basal area equals the *percent CAPs* (fig. 2A).

It is not necessary to break down the tally by size class to determine present stocking, but this breakdown provides a good, quick picture of stand structure. It also is useful later in guiding the stand prescription and in distributing the cut among the size classes. Because the size classes are broad, and because our objective is primarily to provide a picture of average stand structure, it is not necessary to measure the diameters of the sample trees for this tally; visual estimates are satisfactory.

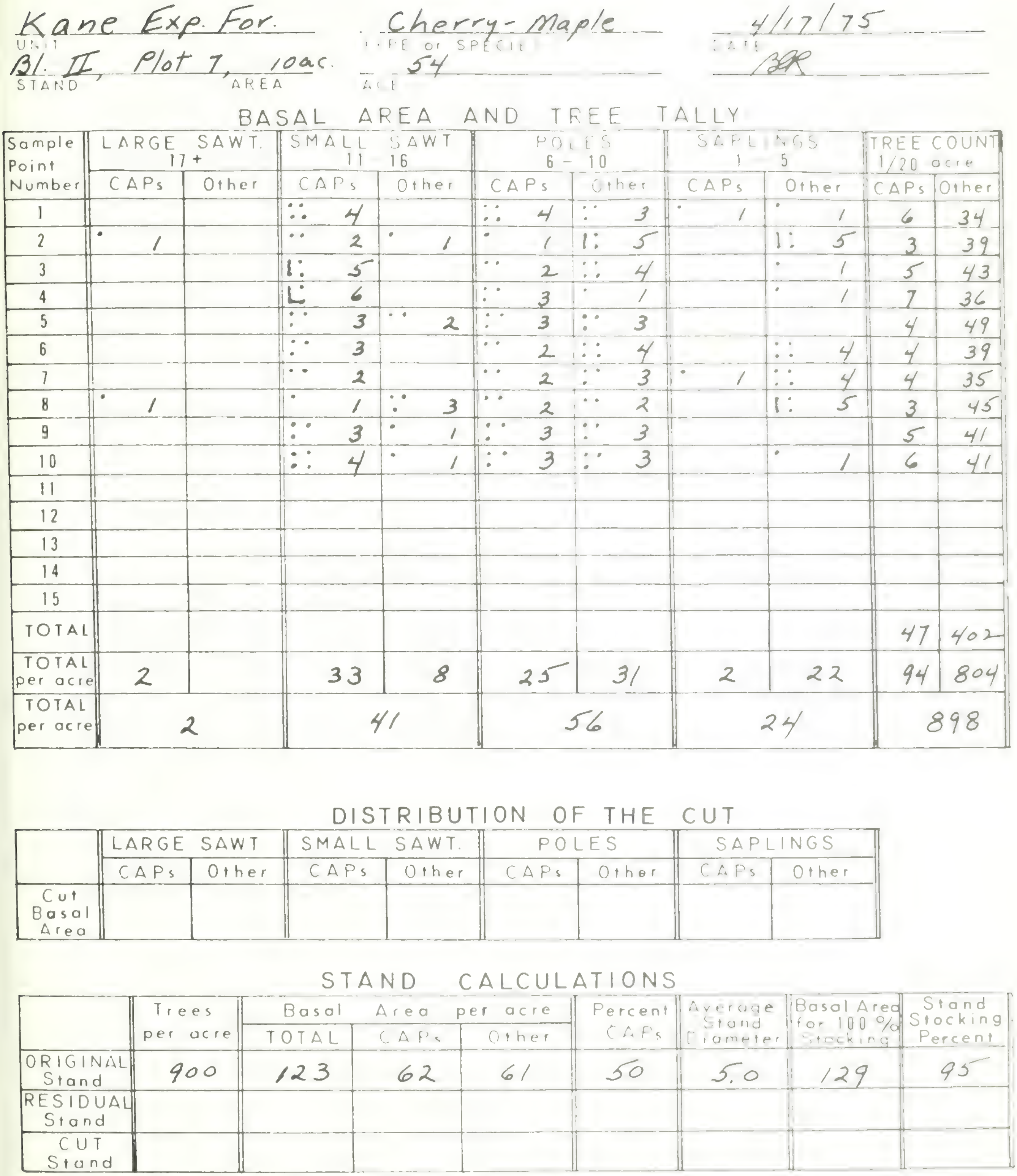
Diameter ranges for the size classes (fig. 2A) may be changed as desired, though they should be consistent throughout a property. Also it may be helpful to identify certain tree classes on the tally—for example, using x's instead of dots to designate culls, or wolf trees, or misshapen members of sprout clumps.

In tallying the basal area, one precaution is especially important: Don't overlook the small trees. The stocking guide is based on all trees that are 1.0 inch in dbh or larger; if the small trees are overlooked or deliberately ignored, the guide will give you a wrong answer.

The Tree Count

We cannot determine the average stand diameter directly from the basal-area data that was obtained on the cruise, *and it must not be estimated visually.* However, there is a direct mathematical relationship between the average diameter and the number of trees per acre for a given basal area. During a cruise, we can obtain a good estimate of basal area per acre by using a wedge prism. Therefore, if we count the trees on enough sample plots to obtain a good estimate of the number of trees per acre, we can calculate the average stand diameter; or we can determine it accurately enough directly from the stocking chart.

The easiest method that I have found for determining the number of trees per acre is counting the trees on 1/20-acre circular plots (radii of 26 1/3 feet) that are centered on the sample points used for the basal-area tally. I place a marker at the center of a plot, go out 26 1/3 feet from that point, and walk around the circumference, counting the trees (live trees only) as the line between me and the center of the



UNIT: Kane Exp. For.
TYPE or SPECIES: Cherry-Maple
DATE: 4/17/75
STAND: Bl. II, Plot 7,
AREA: 10 ac.
AGE: 54
BR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT 11 – 16		POLES 6 – 10		SAPLINGS 1 — 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

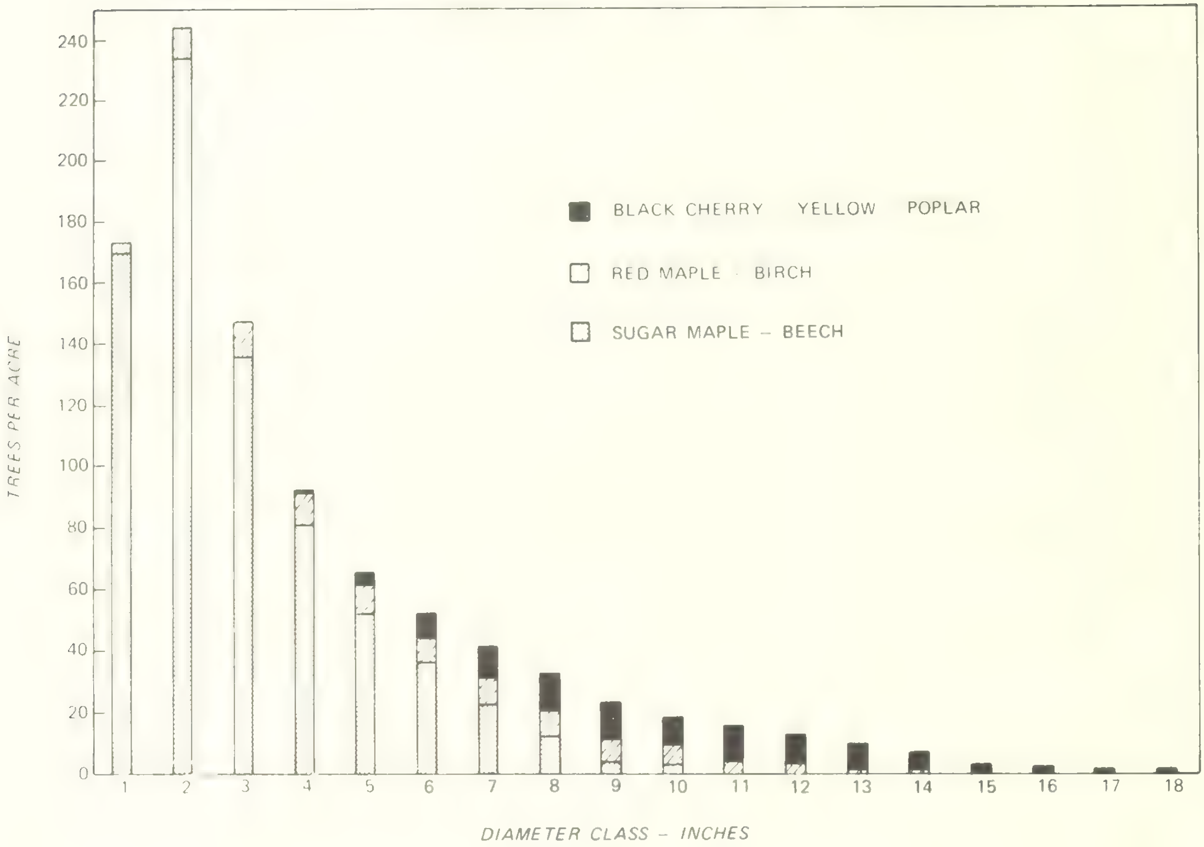
	LARGE SAWT		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand								
CUT Stand								

Figure 2A.—A sample of summary stand tally sheet after cruise.

Figure 2B.—Diameter distribution in sample stand used in figure 2A.



plot passes them. After a little experience (especially learning to mark your starting point) this procedure can be completed for each plot in about 1 1/2 to 2 minutes.

The wedge prism also makes a handy rangefinder for keeping yourself on the plot circumference *(Nyland and Remele 1975).* At 26 1/3 feet, a 10-factor prism will exactly subtend a target of 9.57 inches. The target can be a 9.57-inch length of stove pipe fastened to a pole, or painted rings of different colors spaced 9.57 inches apart on the pole. The former is a little easier to see; the latter is handier to carry in the woods. After a little experience the prism is needed only two or three times per plot for checking borderline trees.There is one precaution: calibrate your prism; not all prisms have the exact factor they're supposed to have.

As with the basal-area tally, it is important to count all trees that are 1.0 inch in dbh or larger because these are the tree sizes that the stocking guide is based on. Failure to count the small trees will guarantee an error. "Trees" means all forest trees including hophornbeam, striped maple, and American hornbeam, but not shrubs such as witchhazel.

Although it is not necessary for determining total stocking, keeping the tree count separately for each of the two species groups will be very helpful later.

Some foresters like to convert the basal-area tally to a tree count. If we know the diameter of each sample tree that is picked up through the wedge prism, we can make a direct estimate of the number of trees per acre through conversion factors that are unique to the diameters. But I have found that this method is unsatisfactory for several reasons:

First, the number-of-trees factor varies widely among the diameters, so visual estimates of diameters are not accurate enough; measuring the diameters will provide a better estimate but this takes more time than counting the trees on a 1/20-acre plot.

Second, even if the diameters of the trees are measured, this method produces a much smaller sample of the trees under 9.6 inches than is obtained by counting the trees on the 1/20-acre plot. For example, to pick up a 1.0-inch tree as a sample tree through the 10-factor wedge prism means that that tree must be within 2.75 feet of the sample point. In effect, 1-inch trees are being sampled on a circular plot that has an area of only about 1/1800 acre. An average of 1 sample point per 2 acres of stand means a sampling intensity of about 3/100 of 1 percent for 1-inch trees, and about 1/10 of 1 percent for 2-inch trees. If the same number of plots are 1/20-acre in size, we can obtain a sample of 2 1/2 percent for all diameter classes.

A third factor of a practical nature further reduces the prospects of correctly sampling small trees with a wedge prism. Forest technicians (and even most foresters) are smart enough not to walk through brush if they can avoid it. Therefore it is a rare sample point that ends up in a clump of saplings, and, consequently, very few 1-inch trees are ever found within 2.75 feet of a plot center (or 2-inch trees within 5.5 feet).

In a typical 50-year-old unmanaged Allegheny hardwood stand, there will be between 700 and 900 trees per acre that are smaller than 9.6 inches, and only about 50 to 80 trees per acre that are larger. With an equal number of samples, the small trees are sampled much more intensively on the fixed 1/20-acre plots than they are by the wedge prism; and with the relatively small number of samples commonly used for stand inventory, fixed plots provide a much better estimate of the total number of trees per acre.

When the cruise is completed, the number of trees is totaled for all sample plots and converted to a per-acre basis (fig. 2A).

Determining Average Stand Diameter

If your pocket calculator has a square-root key, it is now easy to compute the average stand diameter: Basal area per acre divided by number of trees per acre equals the average basal area per tree. Multiply this number by 183.35 (a constant that converts square feet of basal area to the square of a diameter in inches) and take the square root. The result is the average stand diameter (diameter of the tree of average basal area).

The average stand diameter also can be determined directly from the stocking chart (fig. 3). Follow upward along the line that denotes the number of trees per acre until this line intersects the horizontal line that signifies the particular basal area per acre. Note where this point falls with reference to the adjacent slanting lines that designate average stand diameter. The average stand diameter can usually be estimated this way within 1/10 inch, which is accurate enough.

EVALUATING STOCKING AND STAND CONDITION

The sample cruise has yielded the data—basal area, *percent CAPs*, and average stand diameter—needed to determine relative stocking in the stand. The first step in this process is to determine the basal area that would be expected in the stand if it were 100 percent stocked. On the stocking chart (fig. 4) follow down along a line (real or imaginary) that represents the average stand diameter until the line intersects an A-level curve (real or imaginary) that corresponds to the *percent CAPs* in the sample stand. Read the basal area for this point. This is the basal area that a stand of that average diameter and with that *percent CAPs* would usually have if it were at the average maximum stocking found in nature (100 percent). If we divide this basal area into the basal area that was determined for the sample stand, and multiply by 100, we will obtain the *percent stocking* of the sample stand.

By using the summary sheet that results from the stand inventory, we can now make an objective evaluation of stand condition. If we use the stand described on the summary sheet (fig. 2A) as an example, a glance at the sheet will show us that the stand is obviously immature: the average diameter is only 5.0 inches, and there are only 2 square feet of basal area per acre in large sawtimber. It is apparent that the bulk of the basal area is split between the small sawtimber and poletimber sizes, so these are the size classes that we should look to to provide the final crop. We can also see that the stand is very well stocked; in fact it is near the maximum stocking to be expected, so natural mortality must be heavy and net growth relatively low. We can see that half the basal area is in the cherry-ash-yellow-poplar group, and that this group, which is mostly small sawtimber, is run-

Figure 3.—Determining average stand diameter from cruise data.

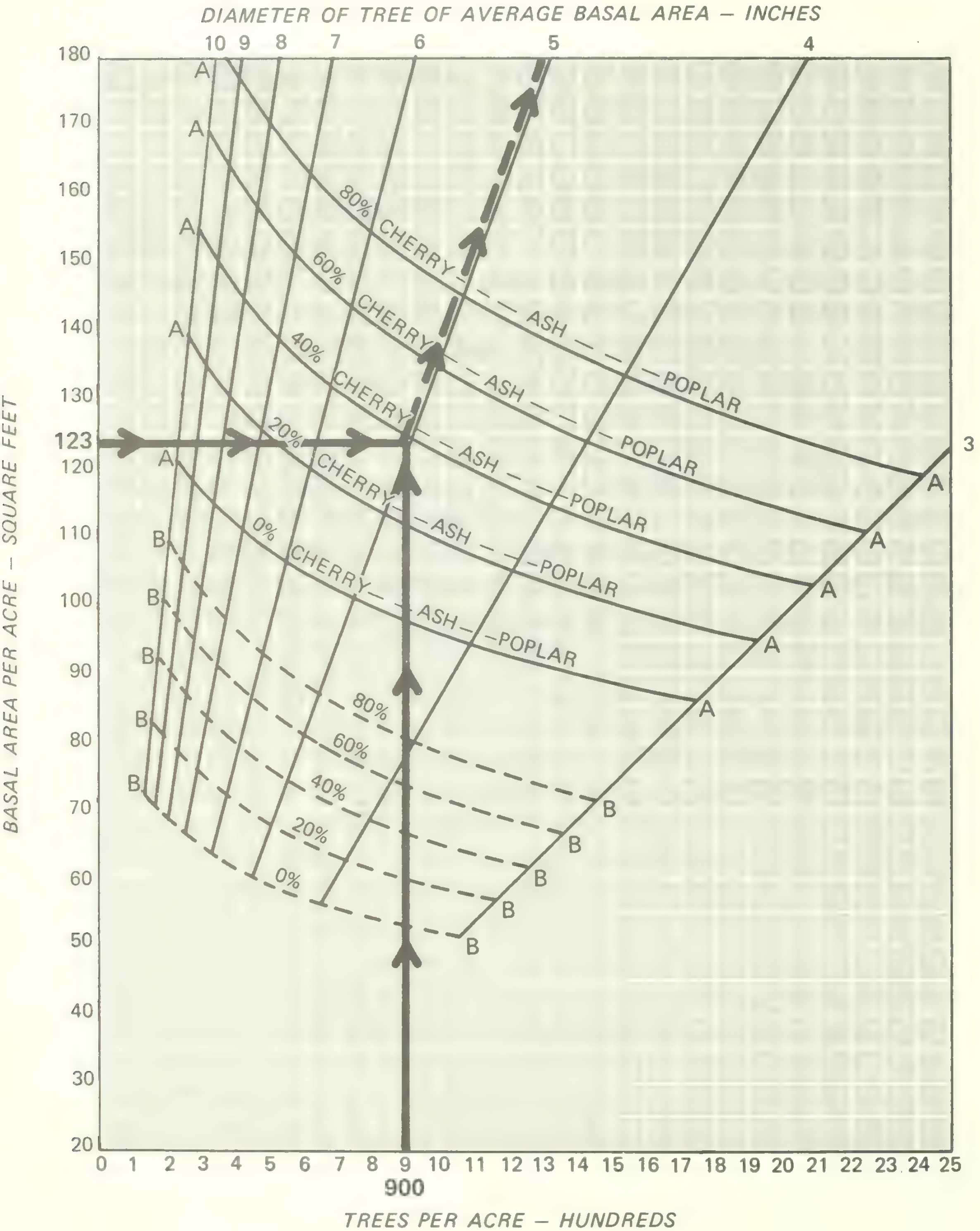
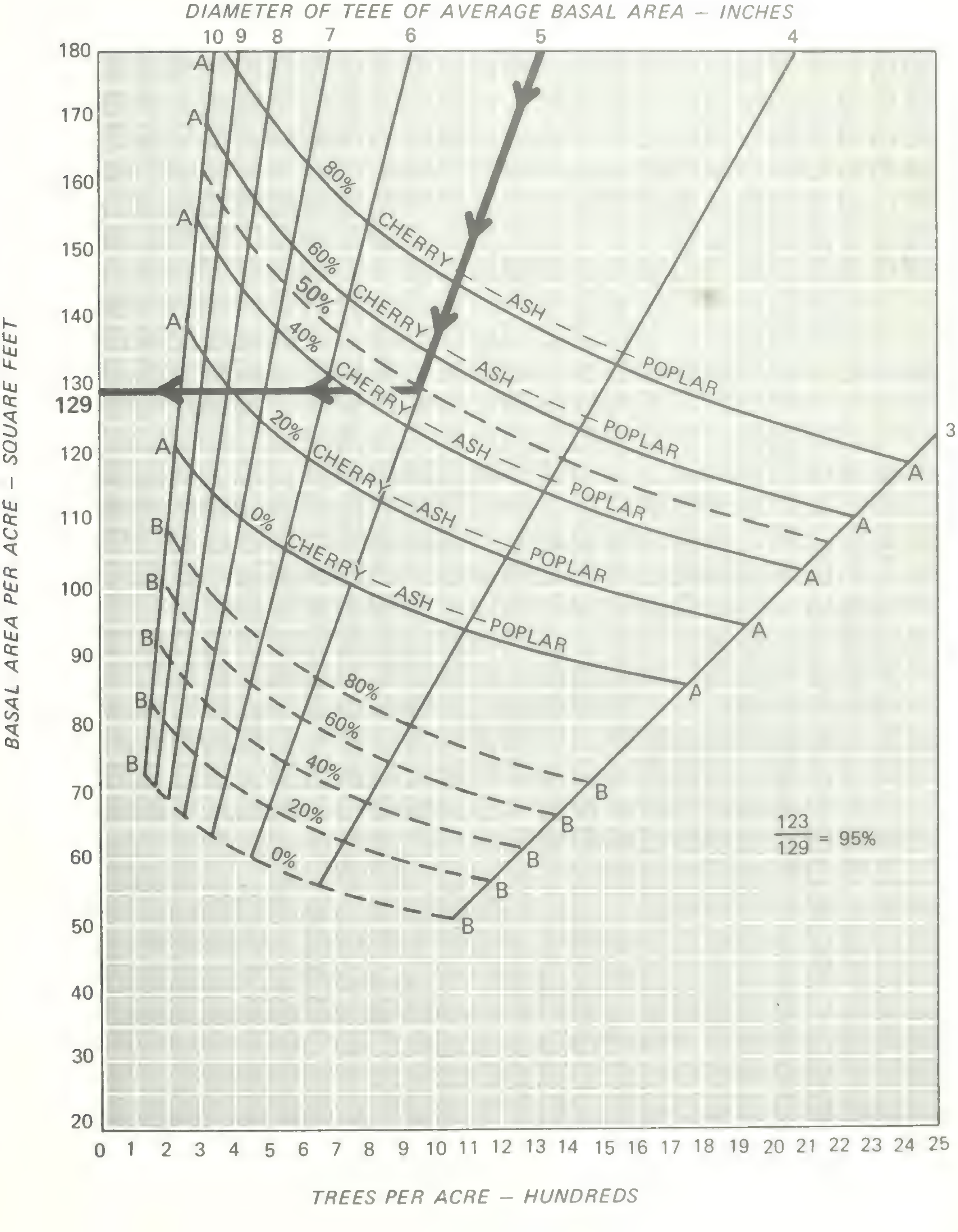


Figure 4.—A-level stocking percent for stand determined from stocking guide.



ning away from the other species. which are mostly poles. If we failed to observe it during the inventory, we can tell from the large number of trees per acre, and the sizeable basal area in the sapling class, that there must be a large number of small trees in the stand (probably 400 to 600 per acre in the 1- to 3-inch range).

All of these factors together provide a typical picture of a middle-aged, even-aged, heavily-stocked stand of excellent composition that is just in the process of growing from poletimber into sawtimber. In such a stand, a thinning is desirable to speed this process.

While many of these factors would be noted by an experienced forester in a casual observation, it would be rare if he noted all of them; and casual observations are notoriously imprecise in determining quantities. The information provided by the summary sheet eliminates much of the subjective judgment and guesswork. The summary also provides a record that will help substantiate current decisions and permit future evaluation of stand development.

GENERAL PRINCIPLES FOR THINNING EVEN-AGED STANDS

The main goal of thinning is to develop the full yield of major products as soon as possible. This is the big payoff for the entire rotation. Therefore each thinning should favor trees from the larger size classes that are of sufficient number and quality to provide a full yield. The bulk of the cutting must be carried out among trees from the smaller size classes, thus satisfying a second goal of thinning: to use the trees that would die during subsequent stand development. Trees from the favored classes should be cut in only those amounts that are necessary to provide the desired spacing and to improve quality and composition as much as possible. So unless there is an overburden of defective large trees, the general rule is that every thinning should cause an increase in the average stand diameter, a decrease in the diameter range, and greater uniformity in the residual stand.

The stocking of previously unthinned natural stands will usually be near 100 percent or A level. At this level of stocking, the net growth of the stand is low. Trees in the upper crown classes may grow fairly well (though rarely at their maximum rate), but much of this growth is counterbalanced by mortality in the lower crown classes and in the species that are least able to survive this intense competition.

Total wood production of a stand is about the same at any degree of stocking between the A level and the B level. However at A-level stocking, this growth is distributed among many trees. Individual growth rates are slow, and some of this growth is wasted on trees that will soon die. At B-level stocking, the growth is distributed among relatively fewer trees. Individual growth rates are faster, and none of the trees will be in danger of dying from overcrowding for some time. Therefore net growth (and the rate of product development) is much better near B-level stocking. So intermediate cuttings should reduce stocking to the B level.

No thinning should be made that reduces residual stocking below the B level because this would reduce the total yield and encourage the development of a heavy understory, or the invasion of the area by herbaceous plants.

The length of the interval between thinnings should depend on how fast stocking and mortality build up. Mortality is usually insignificant until the stand reaches stocking of about 75 percent; then it begins to increase. Mortality rarely becomes serious until stocking reaches about 80 to 85 percent. Thus, a range of stocking of 75 to 80 percent provides a good breaking point in deciding whether to thin. If the stand is stocked at less than 75 percent, growth should be good and mortality should be light, and the margin above the B level may be too small to provide a commercial cut. If stocking in the stand is more than 80 percent, growth rates will be slow, mortality will increase, and there should be enough basal area in the stand above the B level to make the cutting operation worthwhile. When stocking is between 75 and 80 percent, thinning is a matter of judgment. If the stand is readily accessible and markets are good, thin it. If conditions are the opposite, you can wait a few years.

Unfortunately, young stands tend to increase in stocking more rapidly than older stands, which implies different thinning intervals for stands of different ages. This would greatly complicate planning and administration, which are commonly based on 10- or 20-year cutting intervals. This problem can be partially overcome by making lighter thinnings in older stands, and by bringing younger stands to a heavier stocking between thinnings.

Variations Needed for Allegheny Hardwoods

The foregoing principles are broadly applicable to any forest type, but the Allegheny hardwoods are unique in several respects. The combination of rapid-growing, relatively short-lived intolerant species in the same stand with slower-growing long-lived tolerants poses the problem of bringing the latter to merchantable size before all of the former have been cut or lost. The regeneration of the intolerant and intermediate species (except at times for birch and perhaps yellow-poplar) depends on advance reproduction *(Marquis et al. 1975).* But the advance reproduction is short-lived; it comes and goes. This requires that a seed source be present right up to the final harvest cut to maintain a good stocking of advance reproduction of the intolerant and intermediate species. If no advance reproduction of the other species is present at the final cut, the next stand will be composed only of sugar maple or sugar maple and beech, and there will be a consequent loss of value and variety.

A second complicating factor is that stand structure and stand growth vary not only with stand age and stand density but also with the percentages of the various species in the stand. Interestingly, the combination of slow-growing tolerants in the small diameter classes and rapid-growing intolerants in the larger diameter classes creates a reverse J-shaped distribution curve that usually is considered typical of an uneven-aged stand, even though the trees in the stand may differ in age by only 2 or 3 years (fig. 2B). These factors make thinnings much more complex in these stands than they are in stands that have the bell-shaped distribution considered characteristic of even-aged stands.

Growth studies are too recent to provide reliable information on growth rates of Allegheny hardwood species after thinning. Early (3-year) results from thinned 50-year-old stands indicate that there is an increase of only 1 1/4 to 1 1/2 percent per year in *stocking percent.* This rate, if it continues, indicates a minimum cutting interval of about 15 years.

Finally, a number of sites seem relatively "fragile". Stands on the more poorly drained soils seem to represent a tension zone between forest and herbaceous vegetation. Cutting that is too severe, with the high population of deer present—and especially if the cutting is followed by fire—can quickly convert a forest stand to an herbaceous field that may take a half century or more to return to trees.

The general rule that thinnings should reduce stocking to the B level is broadly applicable in Allegheny hardwoods, but there are two important exceptions. One exception is a stand that is threatened by invasion of grass, or especially ferns. A current study by Stephen Horsley supports the growing evidence that these plants produce chemicals that are inimical to the establishment and growth of tree seedlings. The development of a heavy herbaceous cover could seriously retard or even prevent the regeneration of the new stand when the present stand becomes mature. Although we do not yet know the relationship between canopy density and the rate of invasion by herbaceous plants underneath, it seems reasonable that the more open the overstory, the faster the invasion.

A previously unthinned stand is usually near maximum crowding, and average crown size will be small. If this stand is thinned to the B level in one operation, more growing space will be made available than the remaining trees can immediately use, and there will be an interval of several years before the crowns have expanded to fill all of the growing space. In the interim, the extra growing space will encourage the invasion of the herbaceous plants. Therefore, if clumps of these plants are already present (covering 10 percent or more of the ground), or if surrounding areas have a heavy cover of them, I would not reduce the timber stand below 70 percent stocking.

The second exception to the general rule is a stand in the last third of the rotation—say, one that is 60 or more years old. Such stands contain many large trees, and thinning to the B level will result in a wide spacing. It takes a long time for the crowns of a relatively few large trees to fill in the open spaces; in the meantime, much growth may be lost. Therefore, I usually would not reduce the stocking of a previously unthinned stand that is 60 or more years old below 70 percent—even if there is no danger of invasion by herbs—unless the thinning is essential for promoting the maximum growth of tolerant species.

Unless herbaceous plants seem to be a problem, I would not hesitate to thin a stand younger than 60 years of age to B-level (60 percent) stocking regardless of how densely it was stocked initially. Bole sprouting can be minimized in Allegheny hardwoods by selecting clean-stemmed trees to remain.

Also, a fairly heavy release is necessary to obtain a large growth increase in sugar maple and beech. These species grow well when they have sufficient space; but as soon as the stand becomes crowded—especially when there is a dominant canopy of intolerant species—the growth of sugar maple and beech nearly stops. By the time a heavily-stocked stand is 35 years of age, black cherry typically ranges from 3 to 12 inches in diameter; but the largest of the sugar maple that started at the same time will be only about 4 inches in diameter, and the largest beech only 3 inches (Table 1).

To bring any beech and sugar maple to merchantable size before the black cherry is in danger of overmaturity and decline, the tolerant species must have relatively heavy release. Otherwise an expensive Timber Stand Improvement (TSI) operation will be necessary after the main stand is harvested to remove excess maple and beech saplings, and small poles. The alternative is an inevitable conversion of stand type to sugar maple or sugar maple-beech.

DETERMINING MINIMUM RESIDUAL STOCKING

With the principles for making intermediate cuttings in mind, the next step is to determine what the residual stand should contain. There are three things that the prescriber must determine: (1) the level of stocking desired in the *residual* stand; (2)the *percent CAPS* desired in the *residual* stand; and (3) the probable average diameter of the *residual* stand.

To illustrate, I will use the stand that was previously outlined on the summary sheet (fig. 2). This stand is well-stocked, is less than 60 years old, and is not threatened by invasion of herbaceous plants. It can be thinned back to B level stocking (60 percent); this figure is entered on the summary sheet (fig. 5).

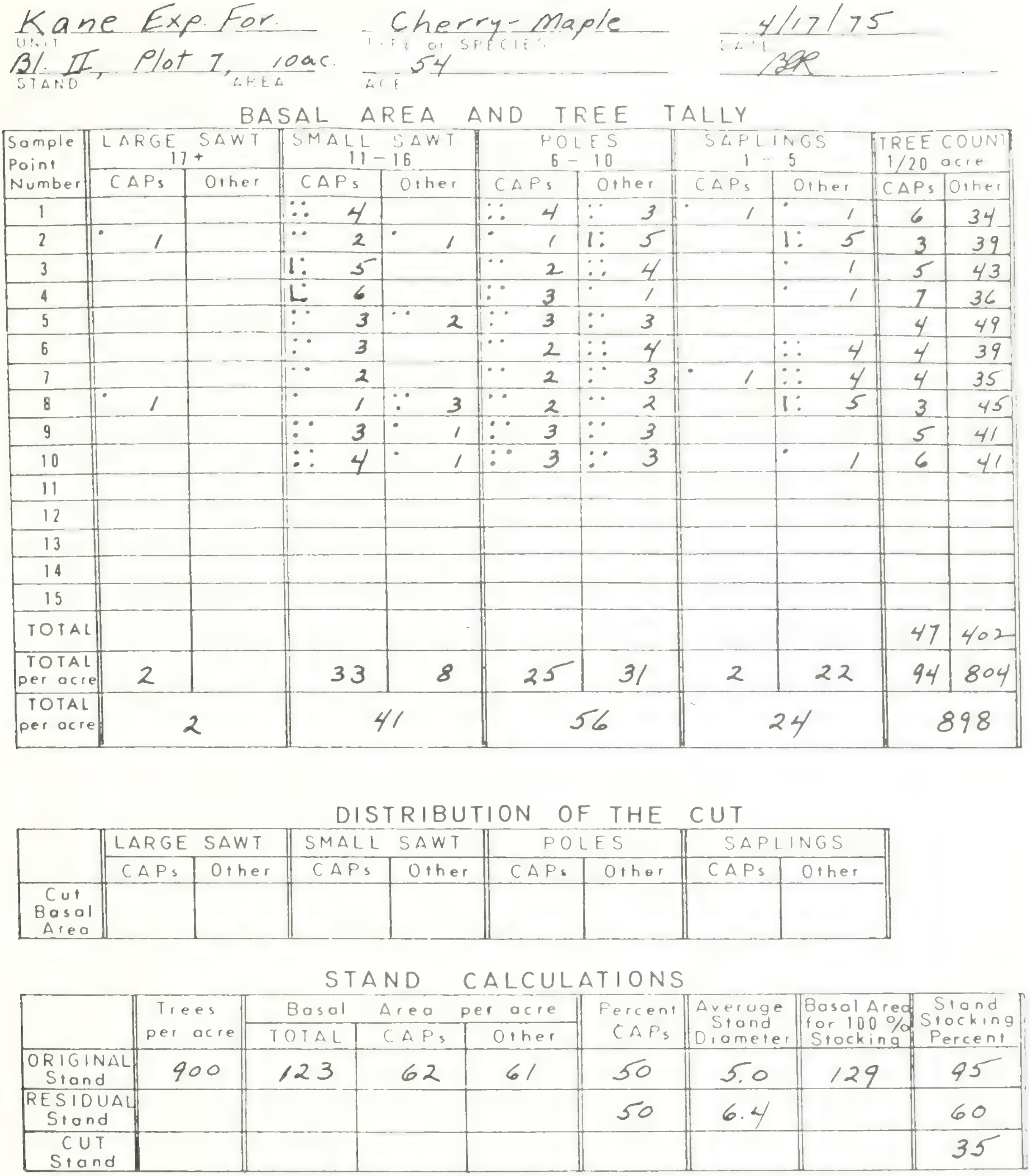
There are few data available to guide the choice of the *percent CAPs* for residual stands. As a practical matter, I have found it difficult to change the *percent CAPs* by more than 10—either way—by thinning. Tentatively, I recommend maintaining CAPs of about 50 percent, so I will plan to keep the *percent CAPs* in the residual stand about the same as it was—at 50 (fig. 5).

It is more difficult to estimate the average diameter of the residual stand than it is to estimate the *percent CAPs*. The change in average

Table 1.—*Diameter of tree of average basal area, by species, in fully stocked, even-aged, and previously unmanaged stands of Allegheny hardwoods (in inches)*

Stand age (years)	Yellow-poplar	Black cherry	Pin cherry	White ash	Red maple	Yellow and sweet birch	Sugar maple	Beech	Entire stand
10	--	--	--	--	--	--	--	--	1.04
20	2.9	3.3	2.9	--	2.4	2.5	1.2	1.1	**2.16**
30	5.3	5.5	4.1	3.5	3.7	3.7	1.9	1.6	3.30
40	8.1	7.7	**5.2**	4.8	5.0	4.8	2.4	2.0	4.46
50	**11.4**	10.1	6.5	6.5	6.4	5.9	3.0	2.4	5.64
60	14.9	12.6	--	8.6	7.8	7.0	3.6	2.7	6.83
70	--	**15.2**	--	11.1	**9.2**	8.0	4.1	**3.1**	8.04
80	--	17.8	--	13.9	10.6	9.0	4.7	3.4	9.25
90	--	20.6	--	**17.2**	12.0	10.0	5.3	3.8	10.46
100	--	23.4	--	20.8	13.5	**11.0**	**5.8**	4.1	**11.69**
Number of stands	16	97	28	23	84	79	101	63	101
R^2 (%)	93	79	54	92	73	77	59	52	80

[a] Limits of data indicated by lowest stand age and diameter figures in boldface.



Kane Exp. For.
UNIT

Cherry-Maple
TYPE or SPECIES

4/17/75
DATE

Bl. II, Plot 7,
STAND

10ac.
AREA

54
AGE

BR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT 17+		SMALL SAWT 11 – 16		POLES 6 – 10		SAPLINGS 1 – 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

	LARGE SAWT		SMALL SAWT		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand					50	6.4		60
CUT Stand								35

Figure 5.—Sample stand tally sheet shows goals for residual stand.

diameter depends on the relative proportions of the large and small trees that are cut. In general, if I thin mostly from below in both species groups, the average stand diameter will increase. In thinning 50-year-old stands generally from below, I find that I can increase the average stand diameter at the rate of about 0.4 inch for each 10 percent stocking that is removed. (In both older and younger stands, the amount is less—about 0.25 inch per 10 percent stocking removed).

In the sample stand, to leave 60 percent stocking means removing about 35 percent stocking:

35/10 X 0.4 inch = 1.4-inch increase.

So I estimate the average diameter of the residual stand to be 5.0 plus 1.4 or 6.4 inches (fig. 5).

Now I can go to the stocking chart and determine the basal area per acre that I need in the residual stand.

Follow down along an imaginary line that represents a 6.4-inch average diameter until it intersects a B-level curve (in this case an imaginary dashed line) that represents 50 percent CAPs (fig. 6). Read the basal area for that point (85 square feet), and enter it on the summary sheet (fig. 7). This is the minimum basal area per acre needed for B-level stocking in a stand that has an average diameter of 6.4 inches and that contains 50 percent CAPs.

From this point drop straight down on the stocking chart to determine the number of trees per acre that should remain—390 (fig. 6). This last step is not really necessary, but it will be useful later.

Now it is possible to determine the basal area per acre that is needed in each species group. With 50 percent CAPs half of the 85 square feet should be in CAPs, the rest in the "other" species (fig. 7). (I rounded them off for easier figuring).

The cut stand can be determined by subtracting the residual stand from the original (fig. 8). The cut should amount to 38 square feet per acre: 19 square feet of CAPs, 19 square feet of "others".

If other than 60 percent stocking is desired in the residual stand, the above procedure must be modified. For example, if 70 percent stocking is desired in the residual stand, the cut will be lighter and the average stand diameter must be reestimated:

25/10 X 0.4 inch = 1.0-inch increase.

This increase added to the original stand diameter equals an estimated average diameter of 6.0 inches for the residual stand.

On the stocking chart follow down along the 6.0-inch average diameter line but find the basal area by using the A-level curves—137.5 square feet (fig. 9). This is the basal area that a 6.0-inch stand with 50 percent CAPs would have if it were 100 percent stocked. For this stand, 70 percent stocking equals 70 percent of 137.5, or 96 square feet.

The number of trees that should remain per acre can be found by following on down the 6.0-inch average diameter line until it intersects a line that represents 96 square feet, and then dropping down vertically as before (490 trees). The residual stand and the cut stand can now be determined as before. (Residual stand is 96 square feet: 48 square feet in CAPs, 48 square feet in others"; cut stand is 410 trees and 27 square feet: 13.5 square feet in CAPs, 13.5 square feet in "others".)

DISTRIBUTING THE CUT

Now you come to the fun part—deciding how the basal area to be cut in the stand will be distributed among the size classes.

As figure 8 shows, we will be cutting a little less than one-third of the basal area, but nearly two-thirds of the trees. (This is the reason for finding the number of trees per acre, as well as the basal area, for the residual stand—it shows the relative number of cut and leave trees.) Obviously, we must cut a large number of small trees to increase the average stand diameter to 6.4 inches.

We know also that we must cut generally from below in both species groups. Each species group has an average diameter of its own, and we need to remove more basal area from below those average diameters than from above them. As a general rule, I try to take about two-thirds of the basal area from below, about one-third from above the average diameter, in each species group. Now, if we just knew the average diameters of each group. . .

If the tree counts were kept separately for the two species groups, the average diameter of each group can be calculated or determined from the chart, as was shown earlier for the entire stand. (Don't try to average the average diameters of the two groups to get the stand average diameter, though; it doesn't work.)

If the tree counts were not kept separately, there are still several factors to guide us. Table 1 shows the average diameter, by species, for even-aged stands of Allegheny hardwoods; from table 1 we can estimate that 54-year-old black cherry will average about 11 inches in diameter.

Another way to estimate this quadratic mean diameter is to go back to the summary sheet (fig. 9). The stand contains 62 square feet per acre in CAPs, distributed as 2 feet in saplings, 25 feet in poles, 33 feet in small sawtimber, and 2 feet in large sawtimber. The midpoint of this basal area—31 square feet—falls in the lower part of the small sawtimber class, about 12 inches. On the average, the midpoint of the basal area will be about 1 inch larger than the average diameter. So again we can estimate an average diameter for the CAPs at about 11 inches.

So in distributing the CAP cut, I will plan to remove about two thirds of the cut basal area—say, 13 square feet—from the sapling and poletimber classes, and the remaining 6 square feet from the sawtimber.

CAP saplings in a 54-year-old stand have no future, so I will plan to remove all of them (2 square feet per acre). Eleven square feet will be removed in CAP poles, and 6 square feet will come from small CAP sawtimber (fig. 10).

Now I can compare the CAP cut, by size class, with what is present in those size classes to determine the relative proportions. I must cut all of the CAP saplings, a little less than half of the CAP poles, and about one out of five small sawtimber.

I'll follow the same principles in distributing the "other" cut. The "other" group has 61 square feet of basal area in 804 trees, which signifies an average diameter of 3.7 inches. So I'll plan to take two-thirds of the cut basal area—about 13 square feet—from the "other" saplings, saving 4- and 5-inch trees where there's a choice. I'll assign the remaining 6 square feet to the "other" poles, figuring on cutting about one out of six.

The above proportions make up only a general guide that will be modified as occasion demands. For example, I do not intend to mark any CAP large sawtimber, but if I run into a wolf tree, or a tree badly misshapen, or one badly damaged by wind or lightning, I'll not hesitate to mark it. Also, I intend to cut all the CAP saplings, but if I find one standing alone in what would otherwise be a hole in the stand, I'll leave it. I want to save all the "other" sawtimber, but if I find three sawtimber that are together in a sprout clump, I'll probably mark one of them. So I'll modify the marking guides as I go along, but I will keep the relative proportions in mind and use them to guide my marking throughout the bulk of the stand where there are no overriding factors.

There is one other important factor to remember during marking: The stand summary provides a good picture of the average stocking condition throughout the present stand. And through our stand analysis procedure, we should now have a good mental picture (after a little experience learning what different stocking percents look like in the woods) of what the residual stand should look like after cutting. However the present stand is not average everywhere; it will contain both dense and sparse patches. Since a major goal of thinning is to make the residual stand more uniform than the original, it is up to the marker to recognize these denser and lighter patches as he comes to them, and make his marking heavier or lighter, accordingly. This may sound difficult, but it is not; all you have to do is keep looking *at the stand* as well as at the individual trees.

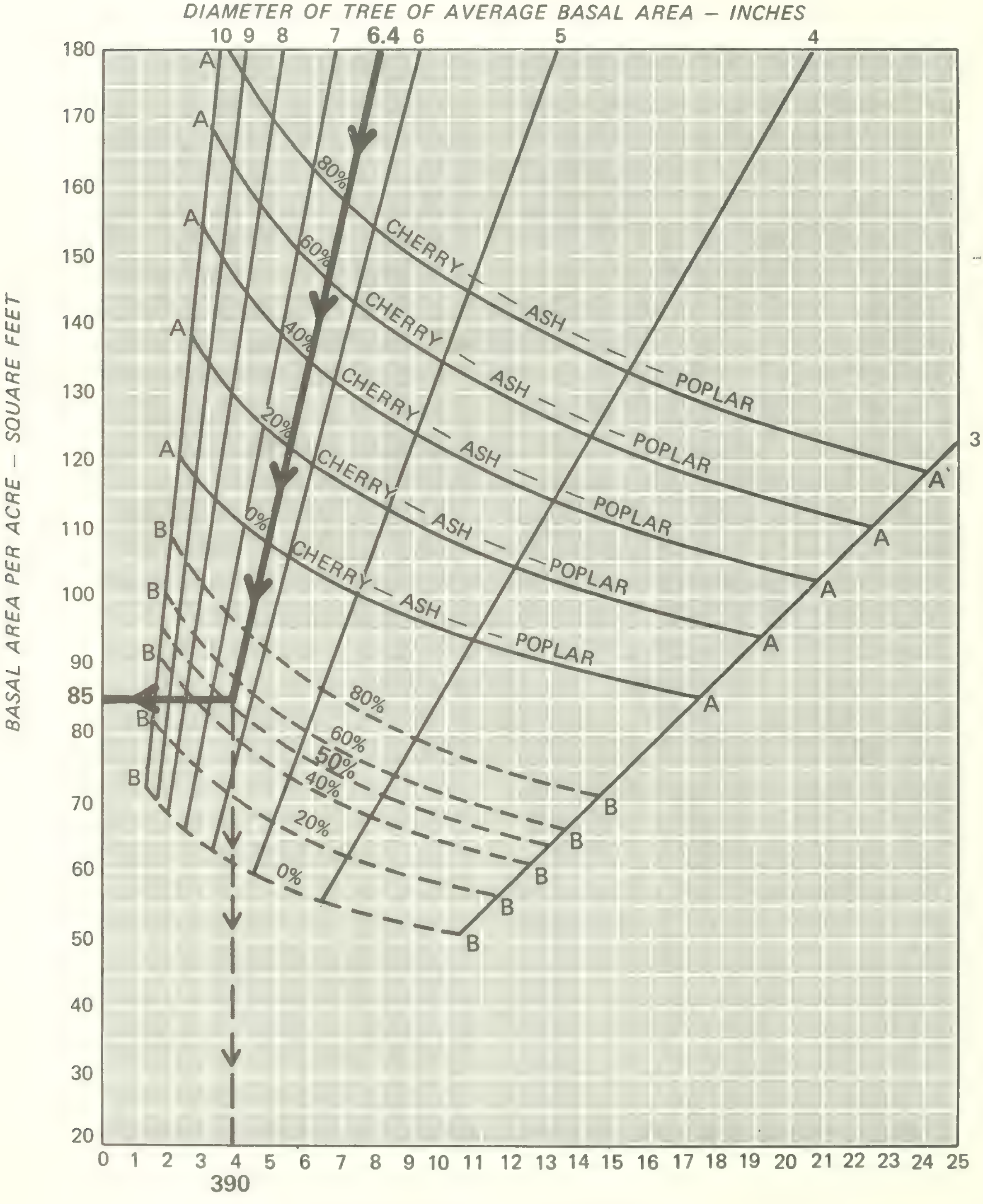
Is the Cut Practical ?

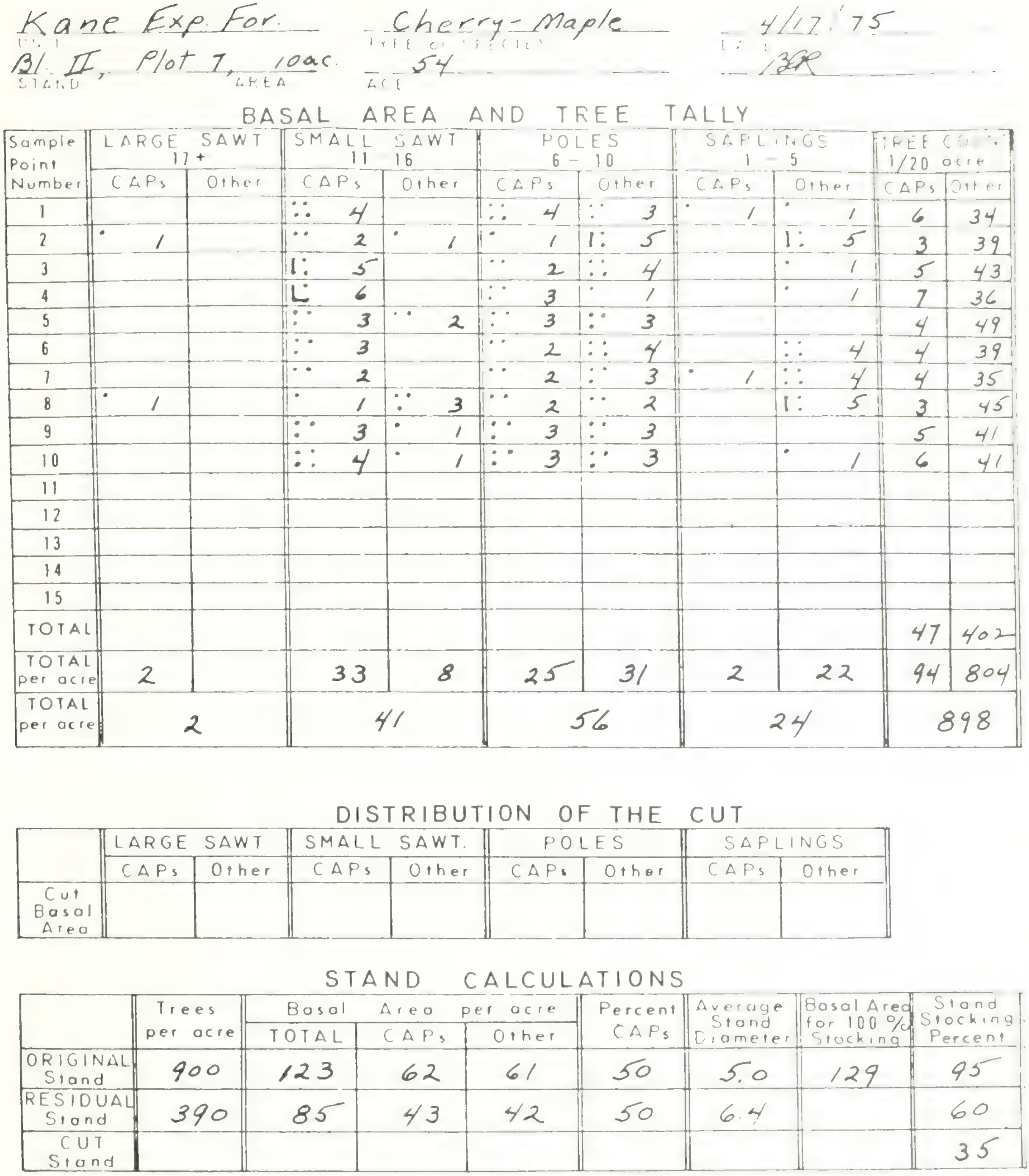
The prospective cut as determined above can be considered the ideal. In this stand it might amount to 400 to 600 board feet and perhaps 5 or 6 cords of pulpwood per acre. Where markets and access are good, it would probably just make a commercial thinning; with poor markets and access it probably would not. Even with a commercial thinning, a TSI operation would have to follow to remove 15 to 16 square feet of saplings.

At this point a compromise may be possible, perhaps by thinning a little more heavily in the sawtimber and a little less in the saplings and poles. If this is necessary in order to make the difference between a commercial thinning or no thinning, I would certainly not say that it is wrong.

But there are two factors to remember. First, you will not get the increase in average stand diameter that was estimated; so it will be necessary to go back and calculate new residual and cut basal areas. Second, if this process is carried too far—so that the final crop is reduced in value or is delayed for one or more

Figure 6.—Determining minimum basal area per acre required for B-level stocking in stand.





Kane Exp. For.
UNIT

Cherry-Maple
TYPE OF SPECIES

4/17/'75
DATE

Bl. II, Plot 7, 10 ac.
STAND AREA

54
AGE

BGR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT 17+		SMALL SAWT 11–16		POLES 6–10		SAPLINGS 1–5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

	LARGE SAWT		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	390	85	43	42	50	6.4		60
CUT Stand								35

Figure 7.—Sample stand tally sheet shows basal area and number of trees per acre desired in residual stand.

Kane Exp For — Cherry-Maple — 4/17/75

Bl II, Plot 7 (STAND) — 10ac. (AREA) — 54 (AGE) — [illegible]

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT. 11–16		POLES 6–10		SAPLINGS 1–5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

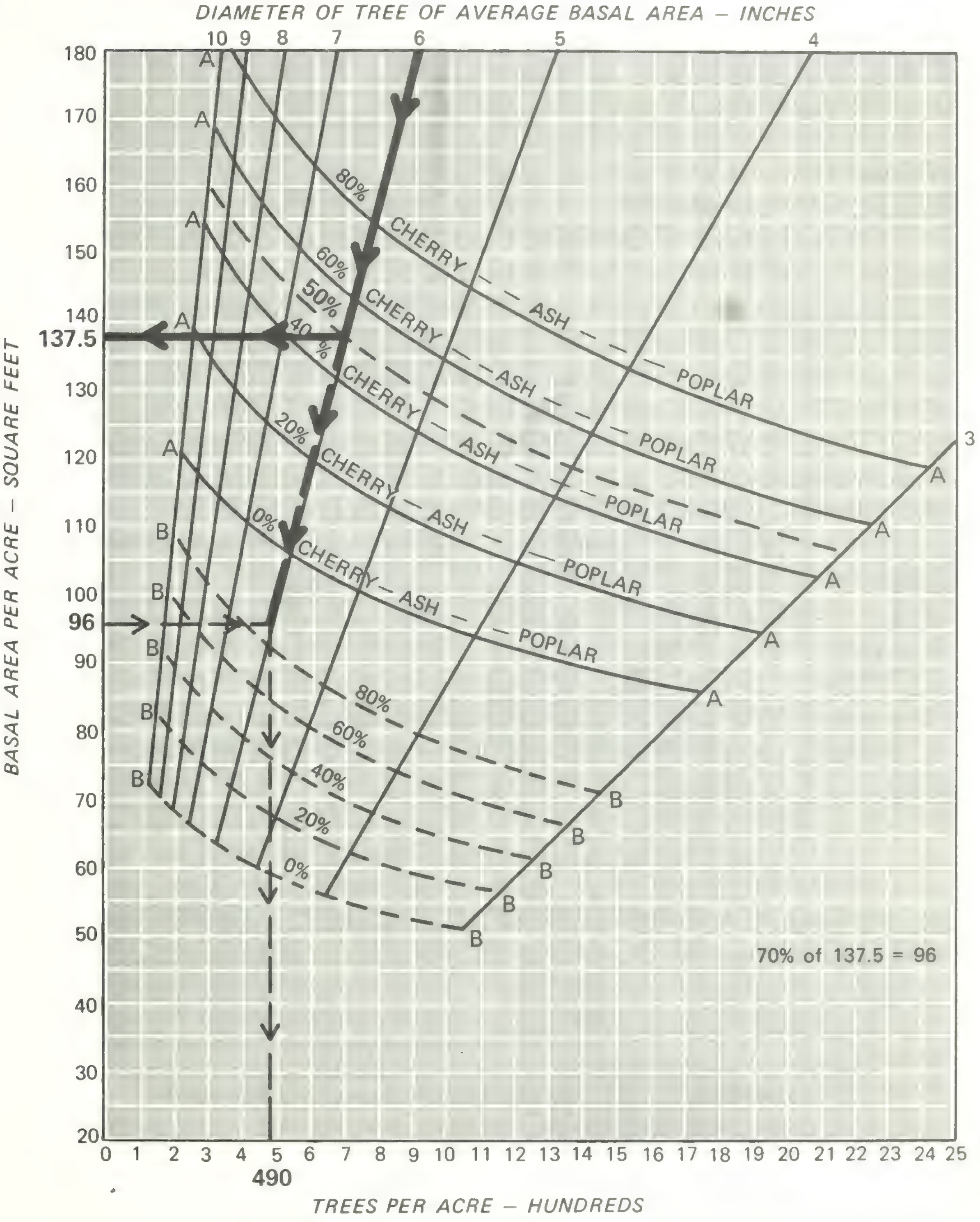
	LARGE SAWT.		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	390	85	43	42	50	6.4		60
CUT Stand	510	38	19	19				35

Figure 8.—Sample stand tally sheet shows number of trees per acre in cut stand and basal-area cut per acre by species group.

Figure 9.—Determining the residual basal area per acre required for any level of stocking.



Kane For — Ch.rry-Maple — 1/17/75

Bl II, — 7. 10ac. — 54 — [illegible]

STAND — AREA — AGE

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT 17+		SMALL SAWT 11 - 16		POLES 6 - 10		SAPLINGS 1 - 5		TREE CO 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

	LARGE SAWT		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area			⑥		⑪	6	②	13

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	390	85	43	42	50	6.4		60
CUT Stand	510	38	19	19				

Figue 10.—Sample stand tally sheet shows distribution of cut, by size class and species group, required to leave desired residual stand.

decades—it becomes not a thinning but a highgrading. In that case you should be aware of this difference and at least use correct terminology.

USE OF THE GUIDE IN SELECTION CUTTING

The stocking guide is based on the principle of allocating growing space to the trees in a stand according to size. If every tree in the stand is allotted sufficient space to live and grow, it should make little difference to the tree whether it grows in an even-aged or an uneven-aged stand (except, of course, that the lack of shade tolerance prevents small CAPs from developing or surviving in either one). Therefore the stocking guide should be as useful for controlling selection cutting as it is for controlling even-age thinnings.

The same tally form and procedure may be used; the only differences are in planning the residual stand and distributing the cut.

Selection cutting is designed to maintain a specified diameter distribution in the residual stand, and various distributions are possible. The classic and more commonly used distributions are based on the ratio between the numbers of trees in successive diameter classes. The ratio has been designated as the Q factor and it usually ranges from 1.3 to 1.6.

When a Q and the largest diameter to be grown have been chosen, the number of trees and the basal area per acre can be determined for each diameter class. Then it's a simple matter to calculate by size class the average stand diameter and the basal area that are needed for any *stocking percent*. Table 2 lists a number of possible basal area goals by size class for Q's of 1.3 to 1.6 for several *percent CAPs*, and at two levels of stocking.[4] The maximum tree size in Table 2 is 24 inches.

To use the guide for selection cutting, you need only select an appropriate basal area goal from Table 2 and list it as the residual stand on the stand inventory sheet. In using the same stand that was used in previous examples, I selected a basal-area goal for a residual stocking of 60 percent with 50 percent CAPs and a Q of 1.5 (fig. 11). (Note that the Q selected determines the average diameter for the residual stand.)

The cut stand is determined by subtraction, as before, and a decision is made as to how the cut will be distributed. Because of the shortage of large sawtimber in the stand, it will be desirable to save as much sawtimber as possible, and some excess poles, to make up the deficit.

The distribution of the cut in figure 11 is a little unrealistic; some sawtimber will undoubtedly have to be removed because of defect, risk, poor form, or spacing. But distributing the cut as shown is the closest we can come to attaining the selection distribution in this cutting cycle without reducing yield.

It would have helped if I had selected a higher Q: the higher the Q the more small trees are required in the distribution; also the higher the Q, the smaller the average stand diameter—so the heavier the cut could be and the more of it that could be assigned to the poletimber and sawtimber classes.

Within a few cuts, of course, the *percent CAPs* will decline and the stand will be converted to sugar maple or sugar maple-beech. However the procedure provides a good picture of how the cut must be distributed to work toward a selection-cutting goal. And at any time it should lead to the best growth that the stand is capable of under the selection-cutting system.

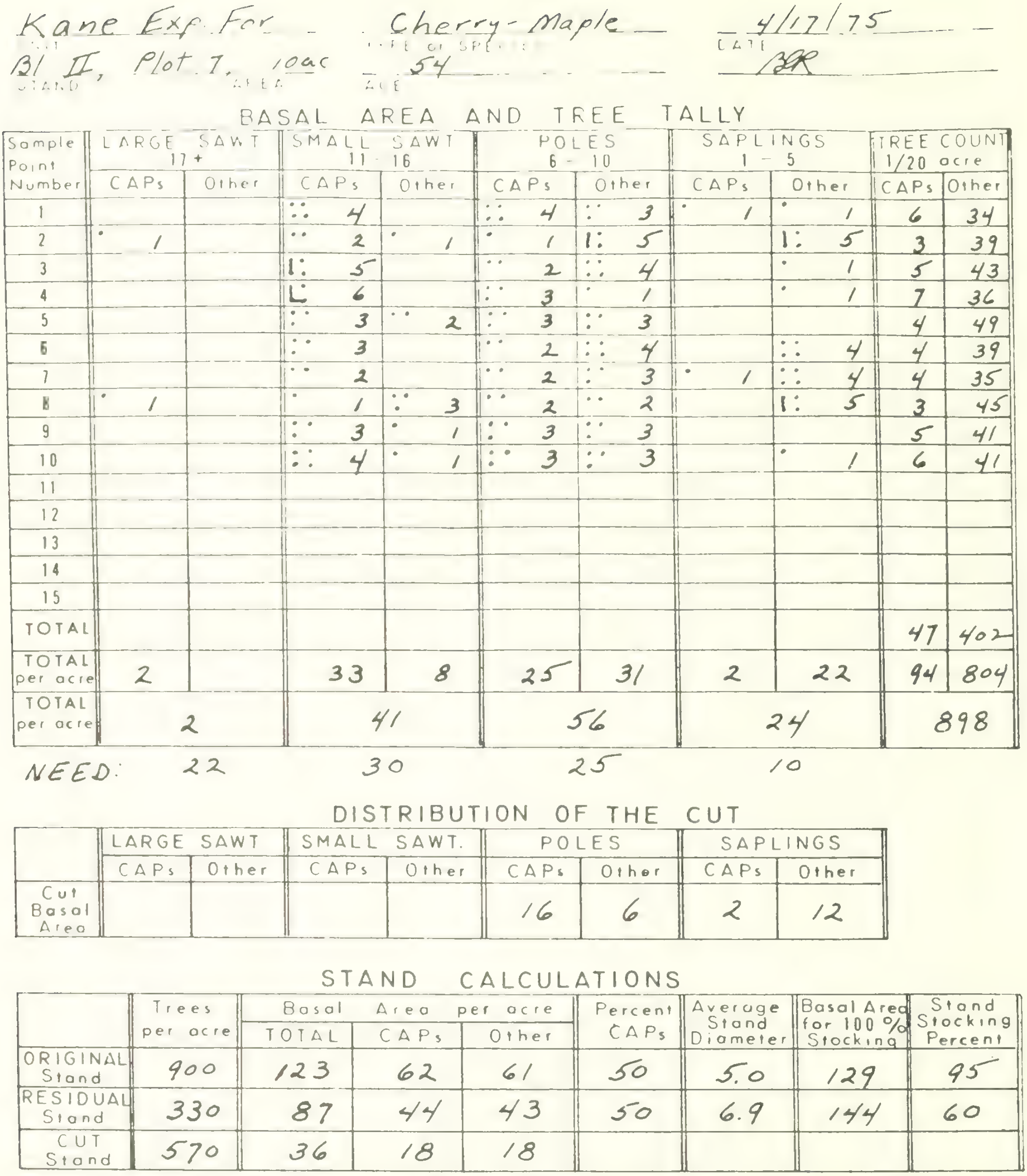
PRECAUTIONS

Region of Applicability

Although this guide was developed from sample stands in a relatively small four-county area in northwestern Pennsylvania, I am hopeful that it will be applicable outside this area. The guide seemed to perform well in three areas in New York State; that is, estimates of original and residual stocking obtained from the guide conformed to visual estimates, and there were no obvious discrepancies. Also, the A level for 0 percent CAPs closely parallels the A level developed for northern hardwoods in New England *(Leak, Solomon, and Filip 1969)*. The latter shows slightly lower basal areas, but this

---

[4] Traditionally, Q factors have been used to show the ratio of trees by successive 2-inch diameter classes, and no trees smaller than 5 inches have been considered. This seems like a sloppy way of doing business, so in preparing Table 2 I used the square root of Q to calculate numbers of trees by 1-inch diameter class, and included all trees down to 1 inch in diameter so that the basal area goals would conform to the stocking chart.



Kane Exp. For — Cherry-Maple — 4/17/75
TYPE or SPECIES — DATE

Bl II, Plot 7, 10ac — 54 — BR
STAND — AREA — AGE

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT 17+		SMALL SAWT 11 - 16		POLES 6 - 10		SAPLINGS 1 - 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

NEED: 22 30 25 10

DISTRIBUTION OF THE CUT

	LARGE SAWT		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area					16	6	2	12

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	330	87	44	43	50	6.9	144	60
CUT Stand	570	36	18	18				

Figure 11.—Sample stand tally sheet shows distribution of cut by size class for selection cutting.

Table 2.—*Basal-area goals for selection cutting of Allegheny hardwoods*

Q factor	Average stand diameter	CAPs	Diameter class (inches)				Total
			1-5	6-10	11-16	17+	
	Inches	%	------------ ft²/acre			---------------	
		RESIDUAL STOCKING AT 60 PERCENT					
1.3	9.0	0	4	14	24	29	71
		20	5	16	27	33	81
		40	5	18	30	37	90
1.4	7.8	0	6	17	23	22	68
		20	7	19	26	25	77
		40	7	21	29	28	85
1.5	6.9	0	8	19	22	17	66
		20	9	22	25	19	75
		40	10	24	28	21	83
1.6	6.2	0	10	21	20	13	64
		20	11	24	23	14	72
		40	12	27	25	16	80
		RESIDUAL STOCKING AT 70 PERCENT					
1.3	9.0	0	5	16	27	34	82
		20	5	19	31	39	94
		40	6	21	35	43	105
1.4	7.8	0	7	20	27	26	80
		20	8	22	31	30	91
		40	9	25	34	33	101
1.5	6.9	0	9	22	26	20	77
		20	10	26	29	22	87
		40	11	28	32	25	96
1.6	6.2	0	11	25	24	15	75
		20	13	28	27	17	85
		40	14	31	30	18	93

can be explained in part because it does not include all of the saplings that are covered in the guide for the Allegheny hardwoods. Nevertheless, if the Allegheny guide is used outside the area of its origin, caution and watchfulness are needed.

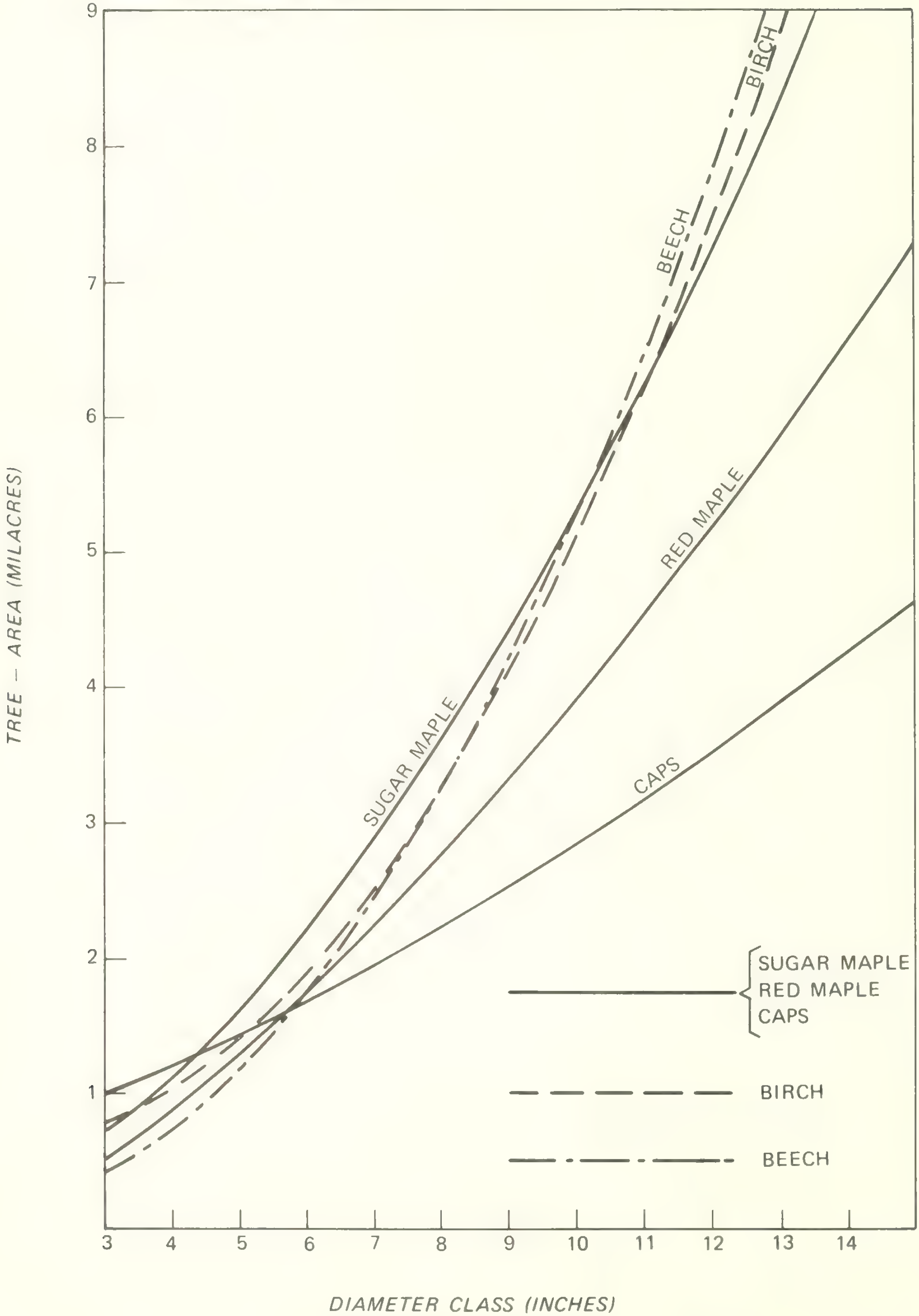
Species Composition

The sample stands that I used had a composition that was fairly typical. Sugar maple, black cherry, and beech were the most common species; red maple and birch ranked next. The stands contained relatively little white ash, yellow-poplar, hemlock, or other species. In fact, there were too few of these trees to treat the species individually in the tree-area equation. My best results were obtained after I lumped ash and poplar with black cherry, and hemlock with "others". This doesn't necessarily mean that ash and poplar have the same requirements for growing space that black cherry has—only that their requirements seem closer to cherry than to the other species. Therefore this guide should be applied cautiously in stands where CAPs are mostly white ash or yellow-poplar.

The same caution applies to stands with a high percentage of conifers. Hemlock, spruce, and other conifers grow in denser stands than cherry; this indicates that they require less growing space at a given diameter. If the guide is used in stands that contain a high proportion of hemlock (10 percent or more), the relative stocking will be overestimated.

Stands that have a large amount of red maple also pose a problem. Using the coefficients obtained from the tree-area equation, I plotted the

Figure 12.—Growing-space allocations for five species groups.



growing-space requirements for the five main species groups. The curves for three of them—beech, sugar maple, and the birches—were very similar (fig. 12); the curve for CAPs was much lower. The curve for red maple fell almost exactly halfway between, so red maple apparently requires more space than the CAPs, but less than beech, birch, and sugar maple.

Ideally, then, it would be desirable to use three species groups rather than two, but this makes the procedure much more complicated. And I don't think the extra precision is worth the effort.

I checked a number of stands with widely different percentages of red maple; I used both the stocking guide and the tree-area equation. Stocking percents were similar for stands that contained up to about 20 percent red maple. (The composition of red maple averaged 15 percent in the 106 sample stands.) In stands that had more than 20 percent red maple, the stocking guide tended to overestimate the *stocking percent.* But there seems to be a relatively simple correction: If the stand contains more than 20 percent red maple, calculate the B level the regular way; then increase it by 1 square foot for every 10 percent of red maple. For example, if the B level is at the 90-square-feet level, and the stand is 40 percent red maple, increase the B level to 94 square feet.

Field Checks on Marking

For either a selection cut or an even-age thinning I strongly recommend that, after marking and before cutting, you make a new stand inventory of the prospective residual stand—at least for the first few stands. If there are serious discrepancies between the planned and the actual stand, you can see what went wrong and correct the marking.

I also recommend that after cutting you make additional checks of stocking. In a short time you will develop the ability to judge relative stocking by eye, which is a great help in marking. After some experience and follow-up checking, I found that I could mark a stand to leave a certain *percent stocking* and usually be within 5 percent. I always make a stand inventory first, and I continue to check myself every chance I get, but it is easier to estimate *stocking percent* than basal area.

Be Sure to Include the Small Trees

It is essential that the understory trees (all saplings 1.0 inch in dbh and larger) be included when using the guide. Failing to do so will result in overestimating stand diameter and underestimating stocking. The B level will then be too high; the amount available for cutting will be reduced; and the real residual stocking will be higher than intended (table 3).

Table 3.—*Effect of excluding smaller trees from basal-area tally on differences in CAPs, diameter, and stocking in residual stand, basal area of permitted cut, and in estimated and actual residual stands*

Item	Minimum dbh included (inches)			
	1.0	1.6	2.6	4.6
Apparent parameters of original stand				
Percent CAPs	48	49	51	58
Average stand diameter (inches)	4.9	5.5	6.7	8.4
Stocking percent	101	96	85	68
Permitted cut				
Basal area (ft²/acre)	43	40	32	14
Estimated residual stand				
Percent CAPs	50	50	50	50
Average stand diameter (inches)	6.5	7.0	7.7	8.7
Stocking percent	60	60	60	60
Actual residual stand				
Percent CAPs	50	49	47	41
Average stand diameter (inches)	6.5	5.5	4.8	4.7
Stocking percent	60	67	76	93

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Roach, Benjamin A.
1977. **A stocking guide for Allegheny hardwoods and its use in controlling intermediate cuttings.** Northeast. For. Exp. Stn., Upper Darby, Pa.
30 p. (USDA For. Serv. Res. Pap. NE-373)

A stocking guide for stands of Allegheny hardwoods (sugar maple or sugar maple-beech with various admixtures of black cherry, red maple, white ash, sweet birch, and other species) on the Allegheny Plateau in northwestern Pennsylvania. Included are procedures for evaluating stocking and stand conditions, thinning even-aged stands, determining minimum residual stocking, distributing the basal-area cut in a stand, and using the guide for selection cutting.

242:535:228.3--176.1

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ABSTRACT

A study of practices for marketing Christmas trees in Winston-Salem, North Carolina, and Denver, Colorado, revealed that such factors as retail lot competition, tree price, consumer traffic, and consumer income were very important in determining a particular retailer's sales. Analyses of 4 years of market data were used in developing regression models for predicting sales of cut trees from retail lots.

DEVELOPING MODELS TO FORECAST SALES OF NATURAL CHRISTMAS TREES

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INTRODUCTION

BECAUSE OF THE SHORT selling season and the perishability of his product, the retailer of natural Christmas trees finds that a good sales forecast is his most important planning tool. Losses sustained by an established retailer or a new one can be substantial if he has little knowledge of his potential sales. If the established retailer errs in his sales forecast and stocks too many trees, he will have trees left unsold on Christmas day and may even depress the market price. If he stocks too few trees, potential sales will be lost.

Unlike most other businessmen, the retailer of natural Christmas trees cannot correct errors in sales forecasts by inventorying surplus merchandise, recouping lost sales, or changing locations. He must study the various potential retail locations in the marketplace and estimate his expected sales performance at each. Once his decision about location and volume has been made, he is virtually locked into it for the short market period of 2 to 3 weeks.

The sales forecasting records of retailers of natural Christmas trees have not been outstanding. Studies in several metropolitan areas show that 10 to 20 percent of all trees available for sale at the retail level remain unsold,[1] *(Pendleton and Garrett 1973, Troxell 1970)*. Certain retailers in these markets have been known to discard two trees for every three they sell. In addition, it is not uncommon to find markets in which as many as one-third of the retailers leave the market after only 1 year *(Pendleton and Garrett 1973)*. A retailer can easily lose a substantial investment if he fails to know his market potential at a given retail location.

To provide retailers with more knowledge about potential sales in a given market area, we undertook to develop a forecasting tool for estimating sales of natural Christmas trees. The tool or model relates tree sales by a single retailer of Christmas trees to those variables that are the most important determinants of his sales. These relationships can be expressed as a predicting equation with the general form:

$$Y = a + bX_1 + cX_2 + \dots$$

where Y is the estimated number of trees that will be sold by a given retailer; the X's are those variables that can affect tree sales, such as price of the tree, merchandising techniques, consumer income, and number of households in the market area. The constants (a, b, c, . . .) measure the relationships between the sales determinants (X's) and the number of trees sold (Y). Such a predicting equation can assist both established and prospective retailers in determining how many trees to stock and where to locate their lots.

This paper describes how the predicting model was developed and tested. It also identifies those marketing factors that strongly influence the success of retailers of Christmas trees.

RESEARCH APPROACH

Sales Determinants

The basic hypothesis of the model is that the number of sales for each retailer of Christmas trees is determined by a set of economic and demographic variables. The economic variables are those that characterize the particular retailer—tree prices, lot location, type of lot, degree of competition, and merchandising methods. The demographic variables characterize the consumers who live in the market area, and include income, number of households, education, number of children and occupation.

A total of 105 economic and demographic variables was analyzed in the study. The data for both sets of variables were collected in Winston-Salem, North Carolina. The data for 48 economic variables were collected in a survey of all retailers of natural Christmas trees in Winston-Salem over a 3-year period, 1967 to 1969. The data for 57 demographic variables were taken from the United States Census of Population and Housing Report for the

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[1] P. V. Ellefson: The 1964 Twin Cities retail Christmas tree market. Unpub. Rep., Schl. For., Univ. MN, 1965.

Winston-Salem Standard Metropolitan Statistical Area *(1960)*.

It was necessary to reduce the large number of variables that were identified as possible determinants of tree sales. This reduction was easily accomplished, because many of the 105 variables are interrelated. For example, total income provides a good measure of an individual's ability to obtain such consumer goods as Christmas trees. Yet, purchase of Christmas trees may also be influenced by other variables, such as family size, value of home, net disposable income, education, and number of rooms in a housing unit, all of which are related to total income. Taken together, these variables provide a more complete picture of a consumer's ability to purchase Christmas trees, but it is not necessary to analyze every one of them. One or two of these variables can represent the entire group.

Factor analysis was used to reduce the 105 variables to a smaller number. The model identified variables that were interrelated and grouped them into factors. Two or three variables were selected from each group to represent the factor. Stepwise regression analysis was then used to select a subset of variables that served as predictors of sales of Christmas trees.

Factor Analysis

Analysis of the 105 variables yielded 19 factors. Table 1 lists one factor and the seven principal variables that the factor model identified as being interrelated. The most important variables from this factor were selected to represent all the variables. The screening of all 19 factors resulted in the selection of 43 of the original 105 variables for subsequent regression analysis.

Table 1.—*Details of seven principal variables interrelated in one selected factor characterized as "Inferior Marketing Practices"*

Description
1. Type of lot—discount store
2. No trees purchased last year
3. Fewer trees sold this year
4. No advertising
5. Little marketing experience
6. Poor tree quality
7. Poor lot quality

Regression Analysis

Regression analysis is a method for describing a relationship between a dependent variable (sales of natural Christmas trees) and a set of independent variables (sales determinants). The "regression" itself is the equation developed to explain this relationship. Stepwise regression was used to develop an equation relating sales of natural Christmas trees to the most *significant* of the 43 sales determinants.

STUDY RESULTS

Using the Models

Predicting equations were developed for each of the three study years—1967, 1968, and 1969. The variables included in each of the three equations, or models, are listed in Table 2. Some of the variables listed represent more than one variable in the actual equation. Model I, developed from the 1967 data, utilized 20 variables as significant determinants of tree sales. Models II and III utilized 18 and 15 variables, respectively. Statistical measures for each of the three models are presented in Table 3.

Of the three models, Model I is the most efficient in describing the data base from which it was created. It explains 89 percent of the variation in sales of trees in retail lots in 1967 and has the smallest standard error of the three models. Model II explains 88 percent of the variance in 1968 sales, but has a larger standard error. Model III is least effective; it explains only 71 percent of sales variation, and has a large standard error.

The variables in the three models reveal those marketing forces that are important to the retailer of Christmas trees. The type of retail outlet and the location of the lot are critical variables. Merchandising, competition among lots, and consumer traffic are important in insuring exposure of the merchandise to potential customers. Tree price and quality, properly paired with the consumer's ability and willingness to pay, set the stage not only for good sales, but for repeat sales to satisfied customers. Good indicators of a consumer's

Table 2.—*Variables comprising predictive equations for sales of natural Christmas trees in Winston-Salem, North Carolina*

Model I	Model II	Model III
Lot type	Lot type	Lot type
Lot location	Lot location	Lot location
Level of merchandising	Interaction of lot type and lot location	Interaction of lot type and lot location
Interaction of merchandising and lot type	Interaction of merchandizing and lot location	Interaction of merchandizing and lot type
Interaction of lot location and lot type	Competition among retail lots	Competition among retail lots
Competition among retail lots	Population in group quarters	Tree price
Consumer traffic	Median family income	Population in group quarters
Tree price	Number of households	College enrollees
Occupation	College enrollees	
Persons per household	Median school years completed	
College enrolees	Value of housing units	

Table 3.—*Statistics of Models I, II, and III*

Model	Number of observations	Number of variables	Variations in tree sales explained (R^2)	Standard error
I	53	20	89	111.9
II	46	18	88	175.3
III	53	15	71	239.4

ability and willingness to pay are his education, the monetary value of his home, his occupation, and his income. All three models included these variables in one way or another in making estimates of a retailer's sales potential. The following examples illustrate how the models utilize the above relationships to predict relative performances of "good" and "poor" retail lots.

An actual retailer in Winston-Salem—who will be given the fictitious name Mr. Fir—sold 20 trees in 1967. He was located in a small business area in a low-income section of the city. Two other lots were within four blocks of his retail lot. Of all retailers studied, the street on which his lot was located had the lowest traffic recorded: 1,000 cars per day. His trees were priced at an average of $2, and were of low quality. He did not merchandise or advertise his trees. It was to be expected that his sales would be low, and the predicting equation painted an even dimmer picture for this lot. Model I predicted Mr. Fir's sales as minus 73 trees!

A second retailer, Mr. Spruce, took an entirely different approach. Mr. Spruce located his lot at a shopping center that had the highest traffic count in the city. There were two other lots close by, but he advertised and merchandised his trees and lot location and kept good-quality trees. As a consequence, he sold 523 trees at the highest average tree price in the city: $5.48. Model I predicted his sales at 545 trees.

In the above examples, the 1967 model predicted sales that differed from actual sales. Although the model is not precise in its estimates, it accurately reflects the effects of "good" and "poor" marketing strategies and lot locations. Predictions of 1968 and 1969 retail lot sales with the 1968 and 1969 models provided results that were similar, although less accurate.

These examples reveal only how well the models predict relationships from data that were, in fact, used to create them. How effective would they be in predicting sales in the same city for a new retailer? And, even more important, could they be used to predict a retailer's sales in another city in another year?

Testing the Models

To test the three Winston-Salem models, each of the equations was used to predict sales for the two other years for which market data were available. In addition, to test predictions made by the model for an entirely different market, an analysis was made of the Denver, Colorado, market.

A 1965 survey of 152 retailers of natural Christmas trees in Denver, Colorado, yielded sales data about the area's market for such trees *(Troxell 1970)*. These data were used to develop a new model similar to those developed in Winston-Salem.

The two metropolitan areas differed significantly, both in demographics and in retail sales of natural Christmas trees. Denver had four times as many households as did Winston-Salem, and a greater average household income. Also, 11 times as many trees were sold in Denver as in Winston-Salem. Ninety-two percent of households purchased trees, of which more than 60 percent were plantation grown.

As expected, each model is most accurate when predicting sales from the market data used in its development. This accuracy can be statistically evaluated by examining residuals (Table 4). Residuals are the differences between what is actually observed in the market, and what is predicted by the model or equation.

The minimum average square residual for the 1967 data set resulted from use of the 1967 model, Model I (Table 4). Similar results were obtained for the 1968 and 1969 Winston-Salem models, and the 1965 Denver Model.

The average square residual for Winston-Salem models was always much larger when predicting sales in the Denver market. Average square residuals of Model I tested on 1968 and 1969 market data were only one-tenth of those created from the Denver data. Also, the Denver model was less effective in predicting Winston-Salem tree sales than Denver tree sales. The average square residuals on the three sets of Winston-Salem market data were three to seven times as large as those occurring from use of the Denver model on Denver sales.

All the models were less accurate in predicting sales from data sets different from the one used to develop them. As expected, the greater the difference in the data sets, the larger the error. The Winston-Salem models were least effective on Denver market data, and the Denver model was least effective on Winston-Salem market data.

CONCLUSIONS

First and foremost, forecasting models do not and cannot guarantee a successful Christmas tree business. Consumer behavior remains somewhat unpredictable. The buyers of Christmas trees undergo changes in attitudes and expectations that cause them to alter their spending habits from one year to the next. These psychological factors cannot easily be quantified and included in predicting equations. Second, the three Winston-Salem models were first attempts to develop methods of forecasting sales of natural Christmas trees; further testing of the methods is necessary.

The predicting equations that have been developed demonstrate the importance of retail lot market strategies, such as merchandising

Table 4.—*Average square residuals from the use of four predicting models on four different sets of Christmas tree market data*

Model	1967 Winston-Salem	1968 Winston-Salem	1969 Winston-Salem	1965 Denver
Model I	**7,567**	65,717	95,028	837,306
Model II	121,913	**18,043**	90,750	776,512
Model III	47,035	60,346	**40,004**	798,621
Denver	1,424,811	1,085,028	2,140,043	**364,399**
Number of Observations	53	46	53	152

Bold type indicates data from which the model was constructed.

and advertising, for increasing sales of trees at the retail level. Further, they establish definite relationships among tree quality, consumer traffic, and competition, and demonstrate how these factors influence both the price received and the number of trees sold.

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5 p. (USDA For. Serv. Res. Pap. NE-374)

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LONGEVITY OF BLACK CHERRY, WILD GRAPE, AND SASSAFRAS SEED IN THE FOREST FLOOR

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ABSTRACT

The results of this study show that (1) black cherry seed remains viable in the forest floor for 3 years, with a small amount of seed germinating after 4 or 5 years; (2) sassafras seed remains viable for 5 years in the forest floor, and (3) some wild grape seed retains its viability for at least 8 years. These results are important to the forest manager in setting up harvest schedules and controlling unwanted species in the new stand.

LONGEVITY OF BLACK CHERRY, WILD GRAPE, AND SASSAFRAS SEED IN THE FOREST FLOOR

THE LONGEVITY of seeds in the forest floor has important implications for the regeneration of Central Appalachian hardwood stands. For example, Sander and Clark (1971) reported that yellow-poplar *(Liriodendron tulipifera* L.) seeds remained viable for up to 8 years in the forest floor of Central States hardwood forests. Clark (1962) found that white ash *(Fraxinus americana* L.) and hackberry *(Celtis occidentalis* L.) seeds remained viable after three winters of storage in the forest floor. Sassafras *(Sassafras albidum* (Nutt.) Nees) seed was viable for only one winter. Leak (1963) also reported that white ash seeds remained viable for 3 years in the White Mountain area of New Hampshire.

Although most of the competition from wild grape is from sprouts from old stems, some vines are established from seeds. For example, Trimble and Tryon (1974) observed 70,000 grape seedlings per acre the first year after cutting. Six years later 278 tree seedlings per acre had grapevines established in their crowns. Although only two trees showed any damage (leader bent over), the authors reported that most of the vines appeared vigorous and capable of doing future damage. Thus, even with a relatively few trees "infested", the potential for grape problems in the next stand had been established.

For several years on the Fernow Experimental Forest near Parsons, West Virginia, natural seed storage of black cherry *(Prunus serotina* Ehrh.), wild grape *(Vitis aestivalis* Michx. and variety *argentifolia* Munson), and sassafras has been studied.

Early results (Wendel 1972) showed that black cherry seeds remained viable in the forest floor over three winters. Of the seeds stored, fewer than 10 percent germinated the first spring, about 50 percent germinated the second spring, and 25 percent germinated the third spring.

This paper reports on continued tests with black cherry and 5- and 8-year results with sassafras and wild grape seed, respectively.

THE STUDY

The field storage area is on a nearly level site under a fully-stocked stand of 65-year-old mixed hardwoods.

The wild grape storage area consisted of four rectangular 2- by 20-foot plots, each divided into fifteen 24- by 16-inch subplots, making a total of 60 subplots. The sassafras and black cherry seeds were stored in individual rectangular 16- by 24-inch plots. All of the plots were constructed of 12-inch wide, 1/4-inch mesh hardware cloth which was forced into a slit 6 inches deep around the perimeter of the plot to keep out burrowing animals (fig. 1).

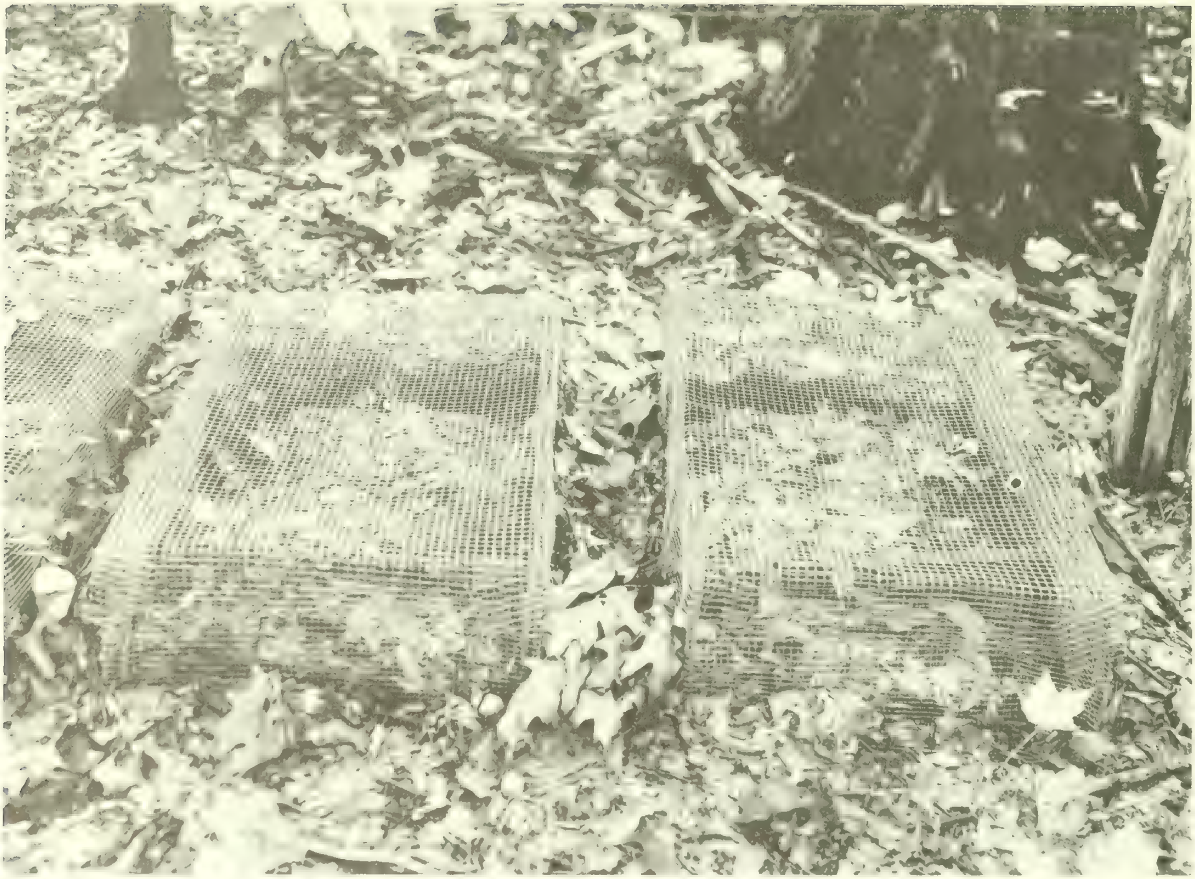

Figure 1.—Field storage plot.

In the early fall of 1968 I collected mature wild grapes from vines in the vicinity of Parsons, W. Va. I counted out 120 lots of wild grapes, each consisting of 70 complete fruits. Sixty lots were broadcast on an 8- by 16-inch area in each of the 16- by 24-inch subplots. The other 60 lots were placed in fiberglass screen envelopes (fig. 2) similar to those used by Clark and Boyce (1964), and placed next to the broadcast-seeded areas in the subplots. Since each grape contains 2 or 3 seeds, the number of actual seeds in each lot ranged from140 to 210. Six broadcast- and six envelope-stored lots were retrieved for testing.

In the fall of 1972, an additional 48 samples consisting of 100 grapes each were stored in fiberglass envelopes. The envelopes were laid on the existing litter and covered with leaves. Four envelopes are withdrawn every 2 years, and the seeds are tested for germination. Germination testing will continue for 24 years or until it is obvious that no more viable seed remains.

In the fall of 1971, 50 sassafras fruits were stored in each of 30 fiberglass envelopes, and 200 black cherry fruits were stored in each of 15 fiberglass envelopes. The following autumn an additional 100 black cherry seeds were stored in each of 15 fiberglass envelopes. When leaf-fall was completed the storage plot covers were removed and litter was added to the plots in an amount equal to the current years' leaf-fall. This procedure was repeated each year for all species.

Enough sassafras seed was stored so that five samples could be tested annually for 6 years. For black cherry enough samples were stored so that samples could be withdrawn annually for 5 years.

Samples were removed from the storage plots in April of each year. The broadcast grape seeds were recovered by picking up all litter and humus above mineral soil and then sifting through a sieve to remove large twigs and leaves. The humus-soil-seed mixture was placed in a shallow tin, watered, kept in a warm room, and observed for germination. Black cherry, grape and sassafras fruits in the fiberglass envelopes were taken from the envelopes, the pulp was washed off, the seeds were counted, and then placed between moistened blotters in the germinator where the temperature was maintained at about 80° F for 12 hours each day. Nighttime temperatures varied with the ambient air temperature. Newly germinated seeds observed in the fiberglass envelopes that were withdrawn for testing were included in the total germination for that year.

Observations were made daily and germination was recorded for a period of 30 days. At the end of the test period, the ungerminated seeds were cut open. Seeds that contained a firm, white endosperm and/or cotyledon were tallied as still viable.

RESULTS

Wild Grape.—For the 8 years of the study, annual germination of grape seeds has been erratic. Less than 1.0 percent of the envelope- or broadcast-stored seed germinated the first year after storage and we did not record any the second year (table 1). However, a cutting test on the second year sample showed that 11.3 percent of the broadcast-stored and 10.8 percent of the envelope-stored seed contained healthy-looking endosperms. With the exception of the spring 1972 broadcast-stored seeds, we have recorded germination of grape seeds every year since 1971.

In general, more of the envelope-stored seed germinated than of the broadcast-stored seeds.

Figure 2.—The fiberglass screen envelope used for storing seed.

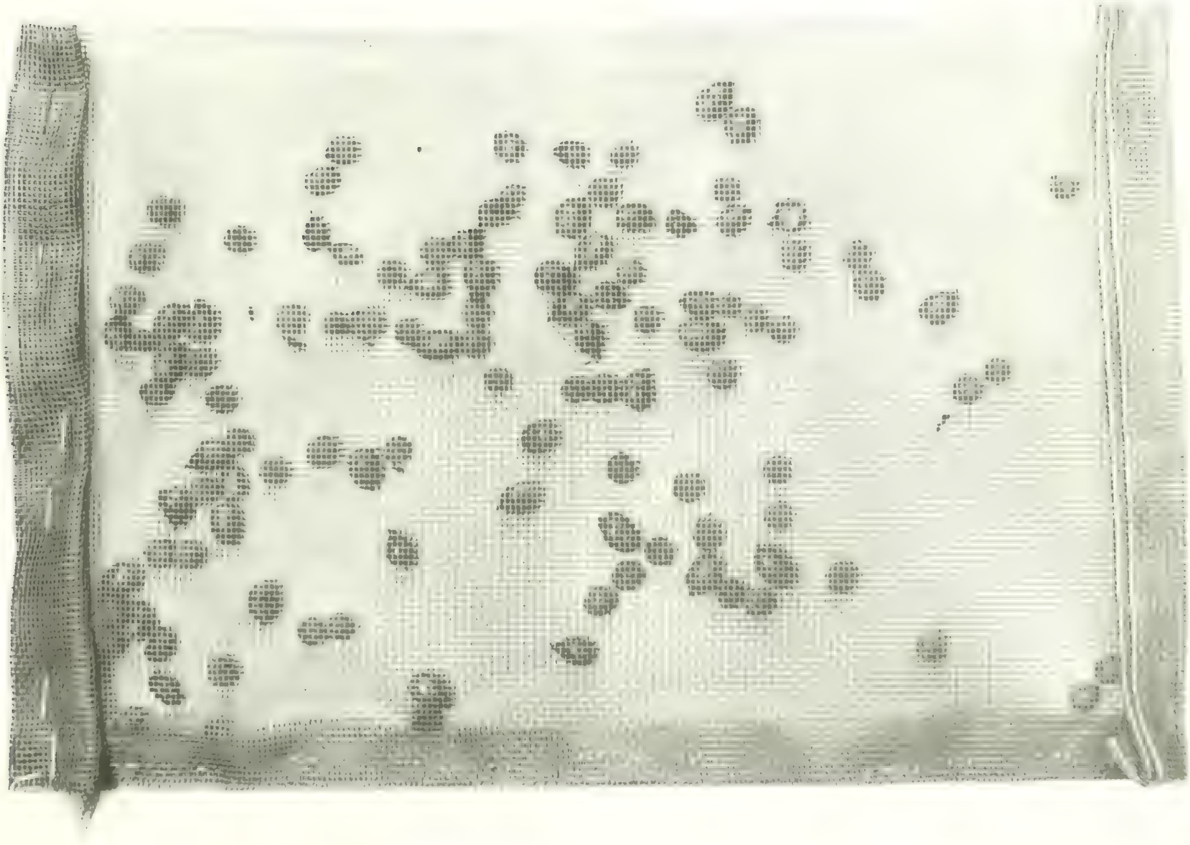

Table 1.—Percentage of germination and healthy endosperm in wild grape seeds

Test year	Broadcast		Envelope-stored	
	Germination [a]	Healthy endosperm [b]	Germination [c]	Healthy endosperm
FIRST LOT—STORED FALL 1968				
Spring 1969	<1.0	—[d]	<1.0	—
Spring 1970	0.0	11.3	0.0	10.8
Spring 1971	2.6	7.8	2.1	4.7
Spring 1972	0.0	4.3	8.0	6.2
Spring 1973	<1.0	1.2	7.2	3.5
Spring 1974	1.7	—	2.3	9.0
Spring 1975	<1.0	—	11.3	7.8
Spring 1976	1.6	—	8.4	6.5
SECOND LOT—STORED FALL 1972				
Spring 1974	—	—	3.0	16.2
Spring 1976	—	—	9.6	9.5

[a] Germinated in shallow tins, in room environment for 30 days.
[b] Determined by cutting test on ungerminated seeds.
[c] Germinated in germinator.
[d] Not tested.

The difference was probably due to the test conditions. Broadcast seeds were subjected to day and night fluctuations in room temperature and humidity whereas the envelope-stored seeds were in the more controlled environment of the germinator. However, cutting test results did not differ greatly between the two types of storage. Cutting tests were discontinued on the broadcast-stored seeds after 1973 because of the difficulty of separating seeds from the humus-soil mixture, and because we felt that the envelope-stored seed was representative of both storage methods.

The amount of grape germination has not shown a steady decline with time, as might be expected, but has been high and low in successive years. This is probably due to natural variation among the various seed lots and possibly some minor variation in storage plot microclimate.

In the second lot of wild grape seeds that were stored in the fall of 1972, germination after the first 2 years of storage was 3.0 percent, with 16.2 percent of the ungerminated seeds containing healthy endosperms. Two years later 9.6 percent of the seeds germinated and 9.5 percent contained healthy endosperms (table 1).

Sassafras.—After five winters of storage, 11.3 percent of the sassafras seeds germinated and 5.7 percent of the ungerminated seed contained

Table 2.—Germination and results of cutting tests in sassafras

Testing date	Average number of seeds stored [a]	Germination	Containing healthy cotyledons
	Number	*Percent*	*Percent*
Spring 1972	50	0.0	78.9
Spring 1973	50	4.0	41.1
Spring 1974	48	12.4	13.2
Spring 1975	48	10.5	16.3
Spring 1976	49	11.3	5.7

[a] Average of 5 samples stored in fall 1971.

Table 3.—Germination and results of cutting tests in black cherry seed

Testing date	Seeds stored	Germination	Containing healthy cotyledons
	Number	*Percent*	*Percent*
FIRST LOT—STORED FALL 1971			
Spring 1972	200	77.4	20.8
Spring 1973	200	26.3	1.3
Spring 1974	200	1.7	0
Spring 1975	200	0	0
Spring 1976	200	0	0
SECOND LOT—STORED FALL 1972			
Spring 1973	100	5.6	92.3
Spring 1974	100	17.8	12.7
Spring 1975	100	7.0	1.0
Spring 1976	100	<1.0	0

firm white cotyledons (table 2). After the first winter, none of the seeds germinated, but about 80 percent contained healthy cotyledons. In general, the viability of sassafras seeds probably does not last more than 6 years, as indicated by the low percentage of ungerminated seeds after five winters of storage.

Black Cherry.—The pattern of germination in the two lots of black cherry seed was not the same. In the 1971 lot, 77 percent of the seeds germinated after the first winter, but only about 6 percent of the 1972 lot germinated after the first winter (table 3). After three winters of storage in the forest floor, there were practically no viable seeds left. Less than 1.0 percent of the second lot of seeds germinated after four winters of storage. This finding confirms results published earlier that most of the black cherry seed germinates within 3 years after it falls from the tree (Wendel 1972), even though a few seeds remain viable for 4 to 5 years.

SUMMARY AND DISCUSSION

Germination of wild grape seed during the first 8 years of the study has been erratic, with no consistent trend toward a decrease with time. After the eighth winter of storage, 8.5 percent of the envelope-stored seed germinated, and 6.5 percent of the ungerminated seeds contained apparently healthy endosperms.

In the second lot of wild grape seed, after 4 years of study, germination was 9.6 percent, and 9.5 percent of the ungerminated seeds contained healthy endosperms.

It appears now that some of the grape seed in the first lot will retain its viability for at least 10 years. With the second lot of seed, we should be able to determine the full longevity of grape seed in the forest floor, because sampling will continue for 24 years.

The data on sassafras indicate that the limit for storage in the forest floor is about 6 years. This is in contrast to results by Clark (1962), who found that sassafras seeds did not germinate after the second winter of storage in the forest litter in Indiana.

The bulk of the germination in the 1971 black cherry lot occurred after the first winter; in the 1972 lot, most of the germination occurred after the second winter. In an earlier study (Wendel 1972), most of the germination occurred after the second winter. Marquis (1975) reported that the bulk of the black cherry seed in northwestern Pennsylvania stands germinates during the first three winters after seedfall. In the West Virginia studies, practically all of the black cherry germination was observed and recorded when the samples were withdrawn from the field storage plots on or before April 22 each year. Ungerminated seeds placed in the germinator failed to germinate even though a cutting test revealed apparently viable seeds. Black cherry requires a rather long stratification at temperatures between 33 and 41° F for after-ripening (Schopmeyer 1974). A couple of relatively warm, mild winters occurred during the test period, which could have influenced the after-ripening process and dormancy of some seeds.

Although individual black cherry trees produce seed every year, good seed crops for entire stands are produced only every 3 or 4 years (Schopmeyer 1974). Marquis (1975) determined that in a 100-year-old stand with 16 percent of the basal area in black cherry, there were 152,000 black cherry seeds in the forest floor. Thus with some new seed being added each year, and some seed remaining viable for 3 years, lack of seed should not be the cause of poor black cherry regeneration after harvest cutting.

When hardwood stands are heavily cut on certain sites, many sassafras and grape seeds germinate. These seedlings and numerous root and stump sprouts of the same species compete with desirable hardwoods. In the case of grape, the vines become concentrated in the tops of small trees and break or bend them down, often killing the tree.

In stands that are scheduled for harvest cutting, sassafras stems of seedling origin could be eliminated from the new stand by removing all of the sassafras trees 6 or 7 years earlier. To curtail the development of stump and root sprouts, the stumps could be poisoned after cutting.

With wild grape the situation is somewhat different. Some of the 8-year-old seed germinated and it appears that some of the ungerminated seed is still viable. We don't know how long grape seed might continue to produce seedlings, but if timber production is the major goal of management, we can cut or poison grapevines as early as practicable in the life of the stand. The source of grape seed would be eliminated and the grapevine roots would die, reducing the number of sprouts and seedlings in the new stand.

The study of wild grape will continue until the longevity of the seed is established. There is a need for information on longevity of some of our other important hardwoods as well as their major competitors. The longevity of fire cherry *(Prunus pensylvanica* L. f.) seed is being studied, and we plan to work with blackberry *(Rubus* sp.) in the future.

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Wendel, G. W.
1977. **Longevity of black cherry, wild grape, and sassafras seed in the forest floor.** Northeast. For. Exp. Stn., Upper Darby, Pa. 6 p., illus. (USDA For. Serv. Res. Pap. NE-375)

The results of this study show that (1) black cherry seed remains viable in the forest floor for 3 years, with a small amount of seed germinating after 4 or 5 years, (2) sassafras seed remains viable for 5 years in the forest floor, and (3) some wild grape seed retains its viability for at least 8 years. These results are important to the forest manager in setting up harvest schedules and controlling unwanted species in the new stand.

181:524 : 176.1

Keywords: Longevity, seeds, wild grape, sassafras, black cherry

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Growth and Survival of Hardwoods and Pine Interplanted with European Alder

USDA FOREST SERVICE RESEARCH PAPER NE-376
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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Abstract

European black alder is recommended for planting on many surface mine spoils in the eastern United States. It grows rapidly on a range of spoil types and contributes to soil enrichment by fixing nitrogen and providing a leaf fall rich in nutrients.

This study evaluated the effect of alder on the survival and growth of five hardwood and five pine species.

After 10 growing seasons, the alder had had little effect on the survival of the interplanted species, but their height and diameter growth were greater in association with alder. Foliar analyses showed that the interplanted species had used nitrogen fixed by the alder.

EUROPEAN black alder *(Alnus glutinosa)* is recommended for planting on many surface mine spoils in the eastern United States (*Funk and Dale 1961, Lowry et al. 1962*). It grows rapidly, reaching heights of 20 to 30 feet in 10 years on favorable sites. The alders contribute to soil enrichment by fixing nitrogen and by depositing a leaf litter rich in essential plant nutrients. These characteristics suggest alder as a nurse crop for hardwoods and coniferous trees.

Finn *(1953)* documented advantages and disadvantages of using black locust *(Robinia pseudoacacia)* as a nurse crop. He concluded that the growth of many species was increased by planting them with locusts. Foliar analysis indicated that the locust was a source of nitrogen for the interplanted species. But the wide-spreading crown and prolific root sprouts of the locust often suppressed or killed slow developing interplanted tree seedlings. This will not be as severe a problem with alder as it has a narrow, columnar crown and does not sprout from the roots.

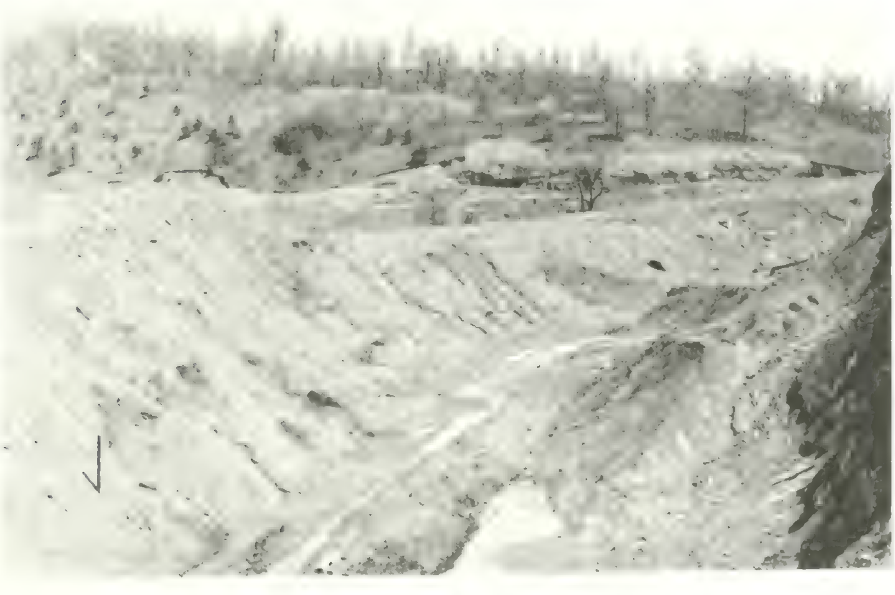
This study was made to compare the survival and growth of five hardwoods and five pine species planted with and without an alder nurse crop. The conclusions, based on 10 years of observation, indicate that alder is a desirable nurse crop.

THE STUDY

The study was established near London, Kentucky, on Lily coal seam spoils. Elevation of the site is about 1,500 feet. One or two contour cuts were made to recover the coal. The spoil was piled on the outside of the cut with no leveling before planting (fig. 1). The strongly to very strongly acid surface spoil, ranging in pH from 3.5 to 5.5, is a mixture of shale and sandstone. There were also occasional patches of toxic spoil with a pH below 3.5.

Three blocks were established on spoils with similar surface characteristics. Each block was divided into two plots (fig. 2). On one plot, five hardwoods and give species of pine were planted. Each 20-tree row was assigned to one of the following species in random order:

Figure 1.—The study area at the time of planting. The spoil was piled on the outside of the cut with no leveling before planting.



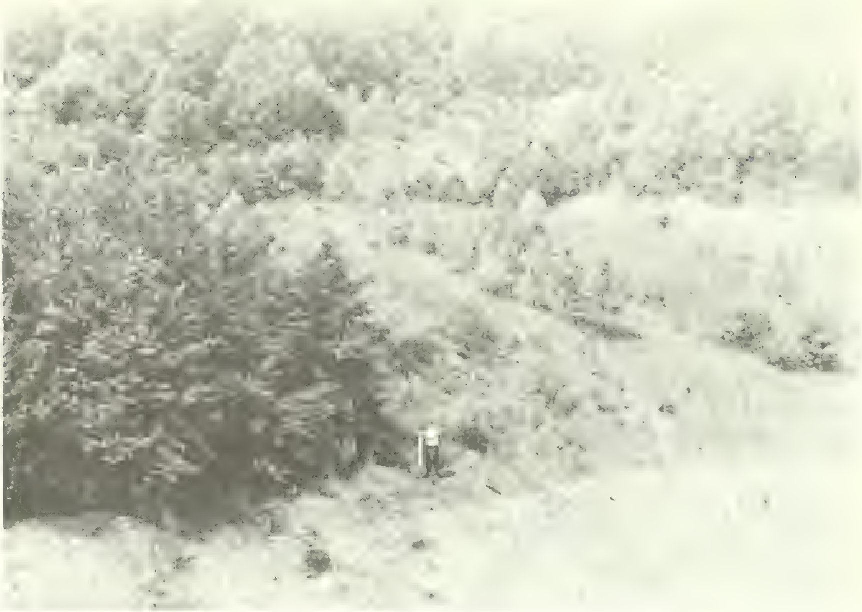


Figure 2.—A block 6 years after planting. The plot planted with alder is on the left; that planted without alder, on the right.

Yellow-poplar	(*Liriodendron tulipifera* L.)
Sweetgum	(*Liquidambar styraciflua* L.)
Sycamore	(*Plantanus occidentalis* L.)
White ash	(*Fraxinus americana* L.)
Cottonwood	(*Populus deltoides* Bartr.)
Shortleaf pine	(*Pinus echinata* Mill.)
Virginia pine	(*Pinus virginiana* Mill.)
Pitch pine	(*Pinus rigida* Mill.)
Eastern white pine	(*Pinus strobus* L.)
Loblolly pine	(*Pinus taeda* L.)

On the second plot, the same species were planted in 20-tree rows alternating with rows of European alder. All species on both plots were spaced 7 x 7 feet. As the experimental design required, the plots with alders were twice the size of the plots without alders.

Measurements

Survival was determined at the end of the first, third, fifth, and tenth growing seasons. Total height of the hardwoods and pines was measured to the nearest tenth of a foot at the end of the third, fifth, and tenth growing seasons. Dale *(1963)* summarized the results of measurements at the end of three growing seasons. Alders were not measured during the study period.

During August of the tenth growing season, leaf samples were collected from each of the test species. Where enough trees had survived, 50 trees of each species were sampled, 25 of those grown with an alder nurse crop and 25 of those grown without it. The trees sampled were chosen from all living trees on the three blocks proportionally. Where less than 25 trees had survived, all living trees were sampled. Leaves or needles were collected from the upper half of the crown on the south or west side. Leaves with obvious insect or disease damage were discarded. Each sample was oven dried and ground in a Wylie mill. A commercial laboratory measured all foliar nutrients except nitrogen; we used the Kjeldahl method to measure foliar nitrogen.

Spoil samples were collected in the spring and fall of the tenth growing season. Thirty samples were collected at random on each plot. The pH was determined from a 1:2 mixture of soil and distilled water with a line pH meter. Total soluble salts were measured electrically with a conductivity meter from a 1.2 mixture of soil and distilled water.

The litter from three 1-foot-square quadrats on each plot was collected, air dried, and weighed to measure litter accumulations with and without alder. These samples were collected at the midpoint between two rows of trees.

RESULTS

Spoil characteristics and litter accumulation 10 years after planting

We compared spoil characteristics and litter accumulation to determine whether alders caused significant changes in the chemistry of the surface spoil during the 10-year study period.

In the spring of the tenth growing season, the pH of the spoils under alders was significantly lower than that of spoils without alders (table 1). A similar analysis in the fall of the same year showed no significant difference in pH between spoils with alders and those without. Spoil pH was lower in the fall than in the spring, both with and without alders.

This may be the result of soil moisture trends and biological factors that influence the formation of acid. The cool weather in the spring reduces microbiological activity in the soil and the frequent rains leach out residual acidity. During the summer and fall, increased temperature accelerates the biological formation of acid. Wetting and drying cycles bring the acidity to the surface by capillary action.

Variations in soluble salt concentrations were similar to pH variations. Salt concentrations were higher under the alders. They were higher in the fall than in the spring. This suggests that the alder cover crop contributes to acidity and to soluble salt concentrations.

There was about twice as much litter on the plots interplanted with alders. Average accumulation under the alders was 27.5 tons per acre, oven-dry weight. On plots without alders, the average was 12.8 tons per acre. Much of the difference is attributed to alder leaf fall.

Survival

Seedlings often die during the first growing season because of their condition when planted or the way they were planted. Site conditions may cause a consistent attrition from year to year. The alders could affect survival when they overtop the interplanted species. In this planting, the trees were overtopped during the fifth or sixth growing seasons (fig. 3). Since the objective of this study was to determine the effects of alder on interplanted species, comparisons of survival during the last 5 years of the study are important.

More cottonwoods and loblolly pines died under the alder nurse crop between the fifth and tenth growing seasons (table 2). The alders overtopped the tallest interplanted species by 5 to 10 feet, and suppression probably caused much of the mortality in these two intolerant species. The survival of the other eight species was not affected by the alder cover crop.

Height and diameter growth

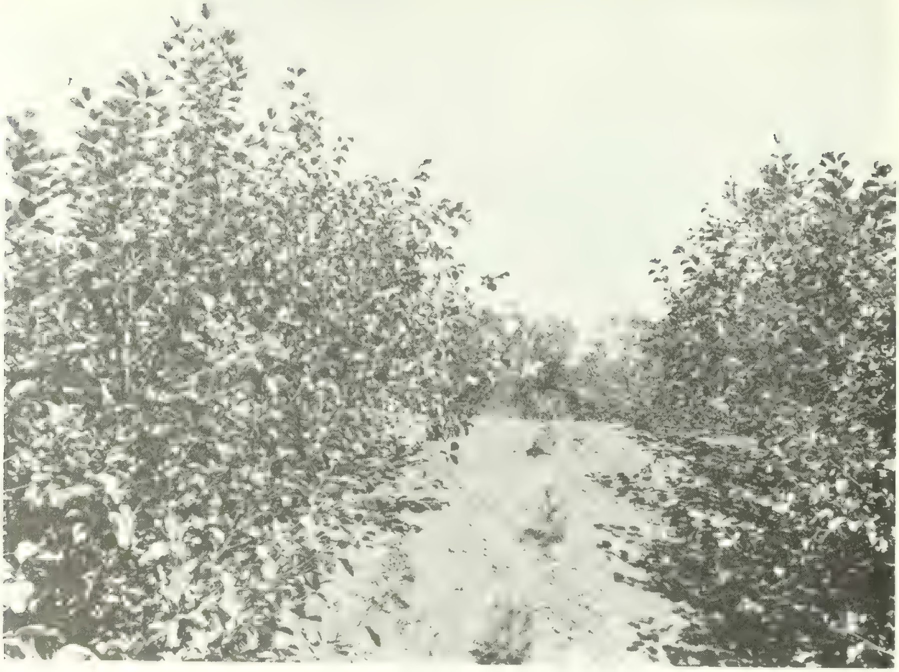
The height growth of 6 of the 10 species was significantly greater under the alder nurse crop 5 years after establishment (table 3). Sycamore, sweetgum, and white ash showed the greatest response to alders. Cottonwood, pitch pine, yellow-poplar, and white pine grew as well without an alder nurse crop.

After 10 years' growth, all species except loblolly pine were significantly taller where they had been planted with alders. Growth differences between trees planted with and without alders were less for cottonwoods than for the other seven species. Cottonwoods and loblolly pines also showed increased mortality when planted with alders. The greatest growth

Table 1.—Mean pH and total soluble salts 10 years after planting

Measurement	Season	Plot 1		Plot 2		Plot 3		Plot average	
		W[a]	WO	W	WO	W	WO	W	WO
pH	Spring	4.0	4.6	5.1	5.1	4.6	4.9	4.6	4.9
	Fall	4.1	4.3	4.8	4.9	4.6	4.6	4.5	4.6
Total soluble salts (mmhos/cm)	Spring	.093	.063	.061	.051	.088	.062	.081	.059
	Fall	.201	.140	.114	.089	.166	.133	.165	.115

[a] W: with alder; WO: without alder.



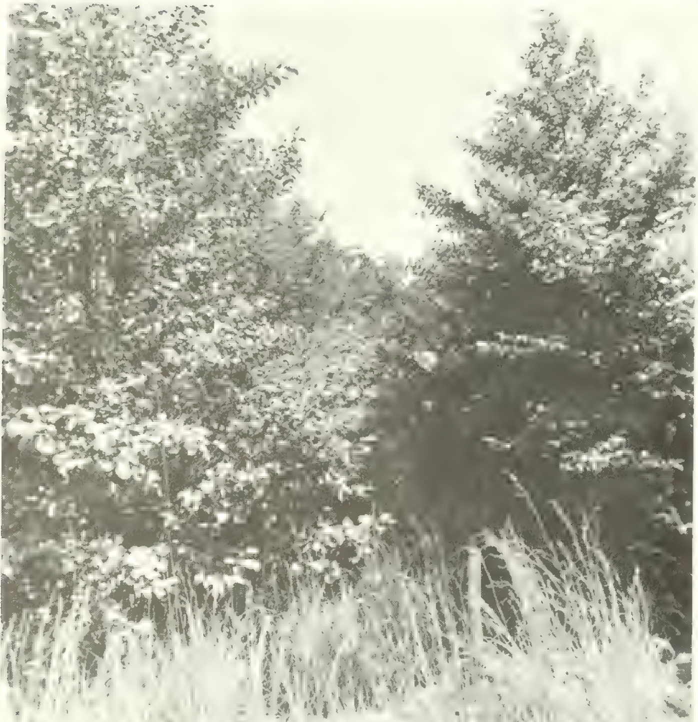


Figure 3.—Alders overtopped the seedlings in this planting in the fourth and fifth growing seasons. The top picture shows 3-year-old white pines interplanted between alders. Below is the same spot during the sixth year.

Table 2.—Percent survival by species at the end of the first, fifth, and tenth growing seasons

Species	Growing season					
	First		Fifth		Tenth	
	W[a]	WO	W	WO	W	WO
Hardwoods:						
Sycamore	32	55	30	53	30	53
Sweetgum	48	68	47	67	47	65
White ash	85	97	85	93	85	92
Cottonwood	68	48	60	40	48	40
Yellow-poplar	52	77	48	68	48	67
Softwoods:						
Virginia pine	93	93	93	93	93	92
Shortleaf pine	73	78	73	75	73	75
Loblolly pine	52	50	50	43	35	42
Pitch pine	88	95	87	93	87	93
White pine	85	88	83	80	83	78

[a] W: with alder; WO: without alder.

Table 3.—Average total height at the end of the fifth and tenth growing seasons (in feet)

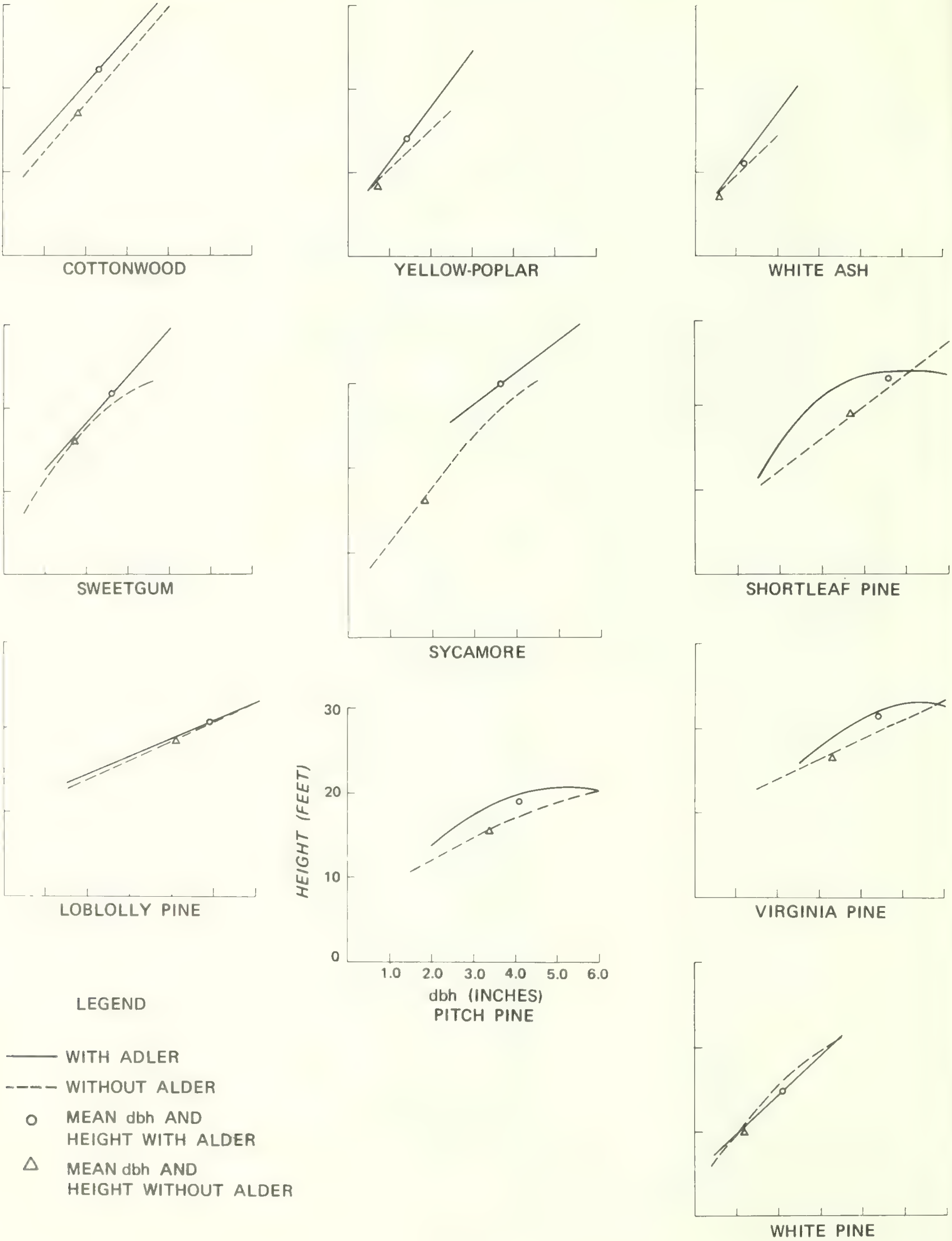
Species	After 5 growing seasons			After 10 growing seasons		
	With alder	Without alder	Diff.	With alder	Without alder	Diff.
Sycamore	12.4	8.1	4.3**	30.0	16.3	13.7**
Sweetgum	8.7	6.7	2.0**	21.6	15.3	6.3**
White ash	7.4	5.9	1.5**	11.1	7.6	3.5**
Virginia pine	8.1	6.7	1.4**	21.5	16.8	4.7**
Shortleaf pine	9.2	7.9	1.3**	23.2	18.6	4.6**
Loblolly pine	10.2	8.8	1.4**	20.7	18.6	2.1
Cottonwood	10.1	9.0	.9	22.1	17.1	5.0*
Pitch pine	6.7	6.0	.7	18.8	15.5	3.3**
Yellow-poplar	4.8	4.3	.5	14.1	8.1	6.0**
White pine	2.8	2.7	.1	14.8	10.0	4.8**

** Significant at 1% level
* Significant at 5% level

Table 4.—Average dbh and height with and without alder nurse crop

Species	dbh		Height	
	With alder	Without alder	With alder	Without alder
	Inches		*Feet*	
Yellow-poplar	1.4	0.7	14.1	8.1
Cottonwood	2.3	1.9	22.1	17.1
Sweetgum	2.6	1.7	21.6	15.3
White ash	1.2	.6	11.1	7.6
Sycamore	3.6	1.8	30.0	16.3
Virginia pine	4.4	3.3	21.5	16.8
White pine	2.1	1.2	14.8	10.0
Pitch pine	4.1	3.4	18.8	15.5
Shortleaf pine	4.6	3.7	23.2	18.6
Loblolly pine	4.9	4.1	20.7	18.6

Figure 4.—Diameter-to-height curves for the 10 species studied.



in response to alders was shown by sycamore, sweetgum, and yellow-poplar.

The average diameter of all species was greater under the alder nurse crop (table 4). Differences in diameter between trees grown with and without alders ranged from 1.8 inches for sycamore to 0.4 inch for cottonwood. Virginia, shortleaf, and loblolly pine averaged about 1.0 inch greater in diameter when grown with alders. This indicates that for many species a merchantable crop could be realized at an earlier age if the trees were interplanted with alders.

The percentage of stems over 4.0 inches dbh provides additional information on the acceleration of diameter growth by an alder nurse crop. Sixty to 80 percent of the stems of Virginia, pitch, shortleaf, and loblolly pine planted with alders were 4.0 inches dbh or larger at 10 years of age. This compares with 25 to 50 percent without alders. Diameter growth of hardwoods was slower. A few sycamores, sweetguns, and cottonwoods had stems 4.0 inches dbh or larger.

Relationship between height and diameter

Regression analyses were used to construct curves to show the relationship between diameter and height for each species with and without alder. In general the relationship between diameter and height was a straight line for hardwoods. Interplanting with alder did not affect this relationship. The pine species showed wide variation in the shape of the diameter-to-height curves. This variance occurred between species and within species, between trees planted with and without an alder nurse crop.

Without alder, cottonwood, yellow-poplar, and white ash had a linear relationship between diameter and height (fig. 4). There were significant differences between the curves for each species. The sweetgum and sycamore data showed a curvilinear relationship described by a quadratic curve. This suggests that these two species may be affected by site characteristics that cause a slowing in height growth for the larger diameter trees. An analysis of covariance showed no significant difference between the sweetgum and sycamore curves. Grouping the data for these two species resulted in a quadratic curve with a correlation coefficient of 0.94. Independently, the correlation coefficients were: sweetgum 0.91 and sycamore 0.94.

When planted with alder all hardwood species showed a linear relationship between diameter and height. An analysis of covariance indicated that data for cottonwood and sycamore could be grouped. The resulting correlation coefficient was 0.89. Before grouping, the correlation coefficients were: cottonwood, 0.91 and sycamore, 0.68. The correlation coefficients for the other species with alder were as follows: white ash, 0.91; yellow-poplar, 0.83; and sweetgum, 0.91.

The relationship between diameter and height was also linear for shortleaf pine, loblolly pine, and Virginia pine growing without an alder nurse crop. There was no significant difference between the curves for Virginia pine and loblolly pine. The correlation coefficients for these species were: Virginia pine, 0.73; shortleaf pine, 0.90; and loblolly pine, 0.82.

Pitch pine and white pine had a quadratic curvilinear relationship between diameter and height when growing without an alder nurse crop. An analysis of covariance showed no significant difference between the curves. The coefficient of correlation was 0.96 for white pine and 0.86 for pitch pine.

When planted with an alder nurse crop, white pine and loblolly pine showed a linear relationship between diameter and height. The correlation coefficients were 0.96 for white pine and 0.72 for loblolly pine. The alder nurse crop modified the diameter-to-height curve for white pine from curvilinear to linear. This is an expression of white pine's tolerance to shading by the alder and an improvement in site factors affecting height growth.

Shortleaf pine, pitch pine, and Virginia pine all displayed a quadratic curvilinear relationship between diameter and height. By analysis of covariance there was no significant difference between the curves. The correlation coefficients were: shortleaf pine, 0.65; Virginia pine, 0.95; and pitch pine, 0.61. The change from linear to curvilinear relationship for shortleaf and Virginia pine when planted with alder suggests the alder may be suppressing height growth. It is possible that wider spacing between these two species of pine and the alder would minimize suppression by the alder.

Foliar analysis

The spoil analyses show that alders reduce pH and increase the concentration of soluble salts. It is also known that alders fix atmospheric nitrogen under favorable conditions. These facts show that alder can alter the chemical and nutrient regimes on a planting site. Foliar analyses were used to identify nutrient differences between species growing with and without alders.

Comparisons of foliar nitrogen showed that nitrogen fixed by the alders is available to interplanted species. All species had higher foliar nitrogen when grown with alders (table 5).

The hardwood foliage had higher concentrations of iron, cobalt, molybdenum, and barium when grown with alder. Concentrations of phosphorus and calcium were lower in the foliage of hardwoods growing with alder.

Nitrogen was the only nutrient found in higher concentrations in the foliage of pines growing with alders. Manganese, strontium, and silicon were lower in pines growing with alder.

Variation in foliar nutrients between species is illustrated by the concentrations of foliar macronutrients. Sweetgum, white ash, and yellow-poplar had significantly higher foliar nitrogen with alder (table 6). Cottonwood had higher foliar magnesium with alder. Variations for the other macronutrients in the hardwood species were either not significant or the foliar nutrient levels were significantly higher without alder.

White pine growing with alder had significantly higher nitrogen, potassium, and calcium. Shortleaf pine had significantly higher nitrogen (table 7). The remaining variations between pines growing with and without alder were either not significant or significantly higher without alder.

Volunteer Virginia pines, similar in size to those on the study plots, grew on an adjacent old field. The old field foliage was higher in

Table 5.—Average concentrations of foliar nutrients with and without alder nurse crop

Foliar nutrient	Hardwoods		Pine	
	With alder	Without alder	With alder	Without alder
Nitrogen, percent	1.17	1.03	1.01	.82
Phosphorus, percent	.27	.38	.19	.18
Potassium, percent	1.10	1.09	.85	.83
Calcium, percent	.84	.96	.27	.30
Magnesium, percent	.51	.47	.08	.10
Manganese, ppm.	514	502	651	721
Iron, ppm.	66	53	51	51
Boron, ppm.	33	39	14	17
Copper, ppm	11	9	4	3
Zinc, ppm.	37	33	32	31
Aluminum, ppm.	278	270	1156	1177
Molybdenum, ppm.	1.79	1.64	1.72	1.71
Cobalt, ppm.	5.32	3.13	1.20	1.12
Strontium, ppm.	32.2	36.0	10.1	13.7
Sodium, percent	1.0	1.1	1.0	1.0
Silicon, percent	40.1	40.4	17.7	21.0
Barium, ppm.	14.3	7.3	1.7	1.7

Table 6.—Concentrations of foliar macronutrients in hardwoods planted with and without alder

Macronutrients	Sycamore		Sweetgum		White Ash		Cottonwood		Yellow-Poplar	
	With alder	Without alder	With alder	Without alder	With alder	Without alder	With alder	Without alder	With alder	Without alder
Nitrogen	0.71	0.82	1.00**	0.65	1.50*	1.21	0.91	0.94	1.75*	1.56
Potassium	1.03	1.18	.77	.69	1.28	1.43	1.27	1.20	1.16	.94
Phosphorus	.18	.18	.20	.39**	.20	.43**	.16	.14	.18	.19
Calcium	.92	.85	.94	1.01	.42	.66*	.95	.98	.99	1.35**
Magnesium	.45	.37	.27	.29	.30	.27	.69*	.59	.82	.85

**Difference significant at 1% level
*Difference significant at 5% level

Table 7.—Concentrations of foliar macronutrients in pines planted with and without alder

Macronutrients	Pine species									
	Virginia		Shortleaf		Loblolly		Pitch		White	
	With alder	Without alder	With alder	Without alder	With alder	Without alder	With alder	Without alder	With alder	Without alder
Nitrogen	0.60	0.52	1.46**	1.13	0.61	0.56	0.77	0.68	1.54**	1.25
Potassium	.73	.74	1.02	1.05	1.04	.95	.69	.74	.69*	.60
Phosphorus	.17	.17	.20	.20	.17	.13	.12	.12	.29	.26
Calcium	.21	.21	.19	.26**	.12	.19**	.22	.25	.61*	.47
Magnesium	.05	.05	.10	.11	.06	.06	.06	.07	.15	.19

**Differences significant at the 1% level
*Differences significant at the 5% level

Table 8.—Concentrations of foliar nutrients in Virginia pine planted with and without alder on surface mined land and growing on an old field

Foliar nutrient	Surface mine spoil		Old field
	With alder	Without alder	
Nitrogen, percent	0.60	0.52	0.85
Potassium, percent	.73	.74	.68
Phosphorus, percent	.17	.17	.17
Calcium, percent	.21	.31	.21
Magnesium, percent	.05	.05	.05
Manganese, ppm.	740	825	379
Iron, ppm.	60	72	64
Boron, ppm.	22	24	22
Copper, ppm.	5	3	8
Zinc, ppm.	40	40	37
Aluminum, ppm.	1100	1086	1097
Molybdenum, ppm.	2.31	2.10	2.17
Cobalt, ppm.	1.15	0.82	1.43
Strontium, ppm.	0	0	1.6
Sodium, ppm.	1.5	1.4	2.0
Silicon, ppm.	33.5	34.2	13.2
Barium, ppm.	.1	.4	6.8

nitrogen, copper, cobalt, and barium (table 8). Trees on the spoil were higher in potassium, manganese, and silicon.

CONCLUSIONS

This study showed important site changes, improved growth, and differences in foliar nutrient concentrations when alder was used as a nurse crop. Specifically:

- Within 10 years, alders significantly reduce spoil pH and increase total soluble salt concentrations. Apparently no reduction in tree growth results from these soil changes.
- At the 7- x 7-foot spacing the alders overtopped and killed cottonwoods and loblolly pines. The survival of the other eight species was not affected by the alder nurse crop.
- Height and diameter growth of hardwoods and pines are accelerated when they are planted at an appropriate spacing with alder.
- Regression analyses demonstrated a straight line relationship between diameter and height for hardwood species growing with and without an alder nurse crop.
- The pine species showed wide variation in the shape of the diameter-to-height curves. A change from linear to curvilinear for shortleaf and Virginia pine suggests that alder suppressed growth for these species. The change from curvilinear to linear for white pine indicates that this species benefited from the alder nurse crop. The relationship between

diameter and height for pitch pine and loblolly pine indicates little or no response to the alder nurse crop.

- Nitrogen fixation by alders increased foliar nitrogen in the interplanted species. There was no other consistent effect on foliar nutrients.

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10 p., illus. (U.S. Dep. of Agric., For. Serv. Res. Pap. NE-376)

European black alder was planted as a nurse crop for five hardwood and five pine species. After 10 growing seasons, the alder had had little effect on the survival of the interplanted species, but their height and diameter were greater in association with alder. Foliar analysis showed that the interplanted species had used nitrogen fixed by the alder.

Keywords: Surface mining, tree species, nurse crop

181.65 176.1 : 174.7 *Pinus*. 176.1 *Alnus glutinosa*. 235.41

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Effect of Nucleopolyhedrosis Virus on Selected Mammalian Predators of the Gypsy Moth[1]

Abstract

Nucleopolyhedrosis virus (NPV) of the gypsy moth was fed to three mammalian predators of the insect: the white-footed mouse, the short-tailed shrew, and the Virginia opposum in the form of NPV-infected 5th instar gypsy moth larvae, polyhedral inclusion bodies (PIB's) mixed in dog food and PIB's mixed in a standard spray formulation. The total amount of NPV consumed by each treated mouse and shrew was equivalent to more than a 40-ha exposure for a 70kg person, assuming the NPV was applied at the rate of 5.0×10^{11} PIB's/ha. Analyses of general body condition, weight, and reproductive efficiency, as well as necropsy and microscopic examination of tissues, indicated that the ingestion of NPV had no short-term effect on these predators of the gypsy moth.

---

[1] The work reported here was funded in part by a U.S. Department of Agriculture-sponsored program entitled "The Expanded Gypsy Moth Research and Development Program."

INTRODUCTION

The nucleopolyhedrosis virus (NPV) of the gypsy moth *(Lymantria dispar* L.) is being developed by the U.S. Department of Agriculture as a biological control agent. During experimental field spraying of NPV for control of the gypsy moth, approximately 5.0 x 10^{11} polyhedral inclusion bodies (PIB's) of this virus are delivered per hectare. The spraying of large woodland areas with NPV presents a potential hazard to resident mammals because they may consume contaminated food, NPV-infected gypsy moth larvae, or both. Our observations indicate that white-footed mice *(Peromyscus leucopus)*, short-tailed shrews *(Blarina brevicauda)* and Virginia opposums *(Didelphis marsupialis)* readily ingest gypsy moth larvae that are in early stages of NPV infection.

Published reports have indicated that other nucleopolyhedrosis viruses have no deleterious effects on either laboratory animals (Aizawa 1954a, Smirnoff and MacLeod 1964, Ignoffo and Hiempel 1965, Ignoffo et al. 1970, Meinecke et al. 1970) or man (Aizawa 1954b).

The NPV of the gypsy moth has been shown to produce no adverse effects when tested against a variety of laboratory animals[2,3,4], but there have been no reports of its effects on the wild mammalian predators of the insect. The following is a report on the responses of the white-footed mouse, the short-tailed shrew and the Virginia opossum to the consumption of gypsy moth NPV

MATERIALS AND METHODS

In March 1975, 40 white-footed mice, 6 short-tailed shrews and 2 Virginia opossums were collected in the field. Mice and shrews were caged on absorbent granules and wood chips in 38-liter glass aquaria with screen tops. Mice were caged in pairs (1 female and 1 male), with cotton as nesting material, but shrews were caged individually. Opposums were housed individually on wood chips in 0.6 x 0.6 x 1.2-m rabbit cages. As a normal diet, mice were fed Charles River[5] mouse chow and sunflower seeds, shrews were fed Alpo dog food and sunflower seeds and opossums were fed Alpo dog food. All animals were allowed at least a 1-week adjustment period. At the end of this period animals were weighed, alloted to test and control groups, and then denied food for 24 hours.

On day 1, each test animal was offered 30 5th instar gypsy moth larvae that had been infected with NPV by allowing 4th instar larvae to feed on a diet containing 1.0 x 10^6 PIB's/ml. These larvae were in their 8th day of infection when fed to the test animals and each contained between 3.5 x 10^8 and 6.0 x 10^8 PIB's. Test animals were fed their normal diet on day 2, again offered 30 NPV-infected larvae on days 3 and 4, and then fed their normal diet through day 11. Control animals were fed healthy 5th instar larvae and normal diet on the same schedule.

On day 12, purified PIB's (Breillatt et al. 1972) were mixed in 1 g of lactose, then were mixed with dog food and fed to test animals at the rate of 1.0 x 10^9 PIB's/animal per day for 3 days. Control animals were fed the same amount of lactose and dog food minus the PIB's. On day 15, all animals resumed eating their normal diet.

On day 18, test animals were offered dog food mixed with the standard spray formulation (CIB) for gypsy moth NPV; each liter contains: Cargil Insecticide Base[5], 123 ml; Chevron Spray Sticker, 23 ml; IMC 90-001, 58.6 g; H_2O, 845 ml and 1.0 x 10^8 PIB's. Test animals were fed at the rate of 1.0 x 10^5 PIB's/animal per day for 3 days. Control animals were fed dog food mixed with CIB minus PIB's. All animals resumed eating a normal diet on day 21.

All animals were weighed at least twice a week during the experiment, and were checked daily for mortality and signs of disease. Male mice were checked regularly for descent of testes, an indication of reproductive activity. On day 32, all animals were killed and fixed whole in 10 percent neutral buffered formalin. After necropsy, the following organs and tissues were

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[2] Litton Bionetics, Inc. 2-year Carcinogenicity Study in Rats. Nucleopolyhedrosis Virus (NPV) of the gypsy moth. Unpublished report 1975.

[3] Litton Bionetics, Inc. Acute Toxicity Tests. Nucleopolyhedrosis Virus of the gypsy moth. Unpublished report 1975.

[4] Litton Bionetics, Inc. Subacute Toxicity Tests. Nucleopolyhedrosis Virus of the gypsy moth. Unpublished report 1975.

[5] Mention of a proprietary product in this paper does not constitute an endorsement by the U.S. Department of Agriculture or the Forest Service.

removed for histopathological examination: brain, spinal cord (mice and shrews), trachea, lung, heart, liver, kidneys, urinary bladder, spleen, thyroid, adrenals, salivary glands, esophagus, stomach, small intestine, pancreas, testes, epididymis, accessory sex organs, ovaries, uterus, mammary glands of lactating females, skin, bone marrow, and lymph nodes. These organs and tissues were processed routinely, sectioned at 6 μm, stained with hematoxylin and eosin, and examined by light microscopy.

RESULTS AND DISCUSSION

Both test and control mice ate at least 90 percent of the larvae offered during the experiment. Shrews ate about 33 percent of the larvae, whereas the opossums ate all of the larvae offered. Test animals ate more than 90 percent of both the dog food mixed with lactose and PIB's and the dog food mixed with CIB and PIB's. The total amount of NPV consumed by each test mouse and shrew was equivalent to more than a 40-ha exposure for a 70-kg person, assuming that NPV was applied at the rate of 5.0×10^{11} PIB's/ha.

Table 1 shows the numbers of experimental animals. The test mice produced five litters during the experiment, compared with only one litter from the control mice. This difference probably occurred because some of the test mice were captured several days before the controls and were better cage-adapted at the start of the experiment. At necropsy, the two groups did not differ significantly in number of pregnant females or in number of embryos per pregnant mouse (table 2.)

For analysis of body weight of the mice and shrews and the number of male mice with descended testes, the experiment was divided into four periods: 1) before feeding of PIB's; 2) after feeding of infected larvae; 3) after feeding of PIB's and 4) after feeding of PIB's and CIB.

There were no significant differences between groups in body weights of mice and shrews (table 3) or in the number of male mice with decended testes (table 4). No differences in general condition of the two groups of each species were seen during the experiment or at necropsy.

Histopathological examination revealed no significant differences between adult animals of the control and test groups. Control mice had higher incidences of periportal lymphocytic infiltration of the liver than test mice (table 5). However, these lesions were minimal in 6 of 10 control mice, whereas 4 control mice and 4 test mice were found to have mild to moderate lesions. This finding indicated an equal distribution between groups of the more severe forms of this lesion.

The test mice had a slightly higher incidence of splenic follicular hyperplasia than the controls, but the difference was not statistically significant. Splenic plasmacytosis occurred more often in control mice than in mice exposed to NPV. This lesion may be related to age, for it also occurred in 5 of 20 mice in the test group born during the experiment. The age of the field-collected mice was not known, but there

Table 1.—Numbers of experimental animals

Group	Treated animals	Born during experiment
Mice:		
Test	17 (8 males, 9 females) [a]	20 (12 males, 8 females) [b]
Control	20 (10 males, 10 females)	4 (2 males, 2 females) [c]
Shrews:		
Test	3 (2 males, 1 female)	0
Control	3 (2 males, 1 female)	0
Opossums:		
Test	1 (adult, male)	-
Control	1 (adult, female)	0

[a] Three of the 20 mice originally in this group escaped during the experiment.

[b] Five litters

[c] One litter; all animals died shortly after birth.

Table 2.—Pregnancy status of mice at necropsy

Group	Number of females	Number pregnant	Number of embryos per pregnant female [a]
Test	9	5	4.6 ± 1.3
Control	10	6	5.2 ± 1.2

[a] Mean and standard deviation

Table 3.—Body weights of mice and shrews (in grams) [a]

Group	Number of animals	Before NPV feeding	After feeding of:		
			Larvae	PIB's	PIB's + CIB
Mice:					
Test males	8	24.3 ± 1.0	23.9 ± 0.9	22.6 ± 0.8	22.6 ± 0.7
Control males	10	25.7 ± 0.6	24.3 ± 1.0	23.9 ± 1.1	23.0 ± 1.1
Test females	9	23.4 ± 2.1	22.7 ± 1.8	23.3 ± 2.6	21.6 ± 2.7
Control females	10	22.8 ± 1.4	22.1 ± 1.1	21.9 ± 0.9	21.2 ± 0.8
Shrews:					
Test	3	19.5 ± 1.6	19.7 ± 0.8	22.1 ± 1.0	21.7 ± 1.5
Controls	3	21.8 ± 1.2	22.7 ± 0.7	23.9 ± 1.0	24.8 ± 1.1

[a] Mean and standard error

Table 4.—Frequency of descent of testes in mice

Group	Before NPV feeding	After feeding of:		
		Larvae	PIB's	PIB's + CIB
Test:				
Number of mice	10	10	9	8
Observations/mouse	2	4	3	5
Total observations	20	40	27	40
Frequency of descended testes at each observation [a]	0.30 ± 0.26	0.15 ± 0.13	0.41 ± 0.34	0.55 ± 0.33
Controls:				
Number of mice	10	10	10	10
Observations/mouse	2	4	3	3
Total observations	20	40	30	30
Frequency of descended testes at each observation	0.30 ± 0.26	0.23 ± 0.14	0.23 ± 0.27	0.58 ± 0.24

[a] Mean and standard deviation

Table 5.—Numbers of microscopic lesions in white-footed mice

					Test animals					
		Control animals			Fed NPV			Born during experiment		
Organ	Lesion	Male	Female	Total	Male	Female	Total	Male	Female	Total
Brain:	Hemorrhage, meniges, mild	0	0	0	0	1	1	0	0	0
Lung:	Interstitial pneumonia, mild	0	0	0	0	0	0	0	1	1
	Parasitic granuloma, mild nematode larvae	0	1	1	0	0	0	0	0	0
	Parasitic arteritis, mild, nematode larvae	0	0	0	0	1	1	0	0	0
Liver:	Fatty change, mild to moderate	1	3	4	3	2	5	2	0	2
	Capillaria hepatica, moderate	2	0	2	0	0	0	0	0	0
	Periportal lymphocytic infiltration minimal to moderate	6	4	10	3	1	4	0	1	1
Spleen:	Follicular hyperplasia, moderate to severe	5	4	9	6	6	12	0	2	2
	Plasmacytosis, moderate	3	2	5	0	2	2	1	4	5
Kidney:	Glomerulosclerosis, moderate	0	0	0	0	1	1	0	0	0
Adrenal Gland:	Lipidosis, cortical, mild to moderate	0	0	0	2	0	2	0	0	0
	Cortical degen- mild	0	1	1	0	0	0	0	0	0
Uterus:	Metritis, suppurative, moderate	-	1	1	-	0	0	-	0	0
Skeletal Muscle:	Sarcosporidiosis, mild	1	1	2	2	1	3	0	0	0
Number of animals examined		10	10	20	8	9	17	12	8	20

may have been a greater number of young animals in the control group.

Other lesions occurred with equal frequency in both groups of mice or were so infrequent as to be considered unimportant. Lymphoid hyperplasia seen in both groups indicated an active immune system in most of these wild mice.

The groups of shrews and opossums were not large enough to reveal any significant differences unless the lesions were very severe. The lesions in these two species (tables 6 and 7) appear to have been spontaneous, with no major differences between control and NPV-treated animals. All the shrews and opossums were heavily parasitized, as were several of the mice, and it appeared that they had adjusted well to these infestations.

In this experiment, only mice were available in large numbers. However, we consider the results for shrews and opossums significant, in

Table 6.—Numbers of microscopic lesions in short-tailed shrews

Organ	Lesion	Control animals			Test animals		
		Male	Female	Total	Male	Female	Total
Liver:	Fatty change, mild to moderate	0	0	0	2	0	2
	Fatty change, severe	1	0	1	0	0	0
	Centrilobular congestion, mild	0	0	0	0	1	1
	Telangiectasis, mild	0	0	0	1	0	1
Spleen:	Extramedullary hematopoiesis, moderate	0	1	1	0	0	0
	severe	1	0	1	1	0	1
Kidney:	Tubular lipidosis, mild to moderate	1	0	1	2	0	2
	Hemosiderosis, moderate	0	0	0	0	1	1
Esophagus:	*Gongylonema sp.*, moderate to severe	2	1	3	2	1	3
Small Intestine:	Nematodiasis, mild	1	1	2	1	0	1
Skin:	Fat necrosis, mild Sebaceous gland hyperplasia, mild	1	0	1	0	0	0
Number of animals examined		2	1	3	2	1	3

Table 7.—Numbers of microscopic lesions in opossums

Organ	Lesion	Control animal	Test animal
Brain:	Meningitis, chronic, mild	0	1
Liver:	Fatty change, mild	1	0
	Congestion, mild	0	1
Spleen:	Extramedullary hematopoiesis, mild to moderate	1	1
	Congestion, moderate	1	0
Kidney:	Glomerulosclerosis, mild	0	1
	Hemosiderosis, mild	0	1
Stomach:	Ulcerative gastritis, moderate to severe, due to *Physaloptera turgida*	1	1
Small Intestine:	Larval cestodiasis, *Taenia sp.*	1	1

light of the massive dose of NPV consumed by the test animals. The gypsy moth is available as a food source to small mammals for only 3 to 4 weeks each year, beginning with 4th instar larvae and ending with pupae. Our observations have indicated that small mammals avoid insects that are heavily infected with NPV. This, coupled with the short life span of both the white-footed mouse and the short-tailed shrew, leads us to believe that the NPV dosage was much higher than these mammals would naturally consume in the wild.

NPV appeared to have no short-term effect on physical condition or reproductive efficiency and caused no consistent differences in the occurrence of gross or microscopic lesions in the white-footed mouse, the short-tailed shrew, or the Virginia opossum, the mammals most likely to ingest nucleopolyhedrosis virus in the wild.

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GOAL PROGRAMING: A NEW TOOL FOR THE CHRISTMAS TREE INDUSTRY

FOREST SERVICE RESEARCH PAPER NE-378
1977

FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082

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ABSTRACT

Goal programing (GP) can be useful for decision making in the natural Christmas tree industry. Its usefulness is demonstrated through an analysis of a hypothetical problem in which two potential growers decide how to use 10 acres in growing Christmas trees. Though the physical settings are identical, distinct differences between their goals significantly influence the recommendations made to them. Included also is a simplified presentation of the general GP model plus a discussion of its applicability to production and marketing problems in the industry.

INTRODUCTION

BECAUSE OF CHANGES in the production and marketing of Christmas trees during the past several decades, the number and importance of management decisions facing producers of natural Christmas trees have increased dramatically. The move from speculative harvests of wild trees to production on a managed plantation basis has brought with it a need to estimate market potential, to make adequate investment analyses, and to schedule various production and marketing activities. In addition, competition from artificial trees has forced the natural Christmas tree industry to better identify consumer preference and to develop and promote its product accordingly.

Not only have they increased in number and importance, but the decisions facing the Christmas tree industry today are far more complex than those in the past. Often many factors, both economic and noneconomic, need to be evaluated. And goals considered important by one group may not necessarily be given the same importance rating by another. Adding to this complexity is the variety of alternatives, often only partially acceptable.

Thus, in many operations a quantitative evaluation of specific alternatives is needed, one that reflects both the available resources and the particular goals of the individual grower. Goal programing (GP) is an analytical tool that seems well suited to such evaluations.

Since its introduction to the decision sciences in the early 1960's, goal programing has been applied to a variety of problems in business, industry, and government. Two recent applications of GP in forestry have addressed problems similar to those of the Christmas tree industry. Porterfield (1974) evaluated several tree improvement programs in southern pine. GP was used to compare projected genetic gains with desired goals for straightness, crown form, specific gravity, volume, and fusiform rust resistance. Where such gains fell short of program goals, GP identified the trade-offs involved in various modifications of the initial goal set.

Similar efforts aimed at improving Christmas tree species are underway in a number of states. Disease resistance, form, color, and needle retention are some of the characteristics in which improvements are being sought. GP should be well suited to evaluating such programs, by measuring achievements in relation to stated goals and identifying the effects of modifications where goals are not met.

Schuler and Meadows (1975) applied GP to the multiple-use management of a 10,000-acre tract on the Mark Twain National Forest. GP helped management personnel select the alternative that best met selected goals for production of timber, recreation, hunting, and grazing within given acreage and budget limitations.

The decision to grow Christmas trees is often only one part of an overall land-use plan developed by a private landowner; he may have a variety of other goals similar to those of the national forest manager. Such goals might include provisions for hunting, recreation, timber production, and wildlife refuge. Like the national forest manager, the private landowner must evaluate his goals in light of various limitations. GP can help him analyze his land-use assignments more objectively. Conflicts in the overall land-use plan, such as between Christmas tree production and recreation, can be readily identified. And if necessary, trade-offs among the goals of the landowner can be clearly delineated before final decisions are made.

GOAL PROGRAMING

GP is simply a mathematical technique which investigates the relationships among a set of desired goals and the resources available to achieve them.[1] Goals may be either economic or noneconomic. Goals are achieved according to priority; the higher priority goals being given precedence in the allocation of resources over those of lower priority. Within a particular priority level, subgoals may be specified by use of a weighting factor.

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[1] Those interested in a more comprehensive review of goal programing and a discussion of how it differs from linear programing should see Lee's (1972) text.

In its most basic form, GP consists of an objective function which minimizes deviations from specified goals:

$$\text{minimize } Z = \sum_{i=1}^{n} w_i P_i (d_i^- + d_i^+) \qquad [1]$$

and a set of constraint equations:

$$\sum_{j=1}^{m} a_{ij} X_j + d_i^- - d_i^+ = b_i \qquad [2]$$

The constraint equations specify various goal or physical constraint levels (b_i). Assignment of activities (X_j), which may be in the form of hours of labor, dollars, trees, acres, etc., is dictated by the objective function, which minimizes both negative (d_i^-) and positive (d_i^+) deviations from specified goals according to their respective priority (P_i), and a weighting factor (w_i), if any. Production coefficients (a_{ij}) represent the relationship between the particular activity and the magnitude of its contribution to achieving the specified goal.

AN EXAMPLE

In the following example two growers—Mr. Leisure and Mr. Profit—use GP to analyze the requirements and potential returns of growing Christmas trees on 10 acres of land. Although hypothetical, their situations reflect many of the same considerations regularly faced by Christmas tree producers.

The large investments and long-term commitments required to grow Christmas trees make it desirable that growers develop and consider various production and marketing alternatives long before any trees are sent to market, in fact, the chances of success are improved if these alternatives are analyzed before the first tree is planted. A few obvious questions are: What species should I grow? How much labor shall or must I invest? What are the capital requirements and limits of the operation? What return can I expect?

However, the decisions will reflect more than purely economic considerations. Growers range from pure businessmen to pure hobbyists with many degrees in between. While some growers would simply choose the tree species that provides the greatest dollar return, others would choose a lower return with a guarantee that a variety of trees would be grown, or that idle land or time would be utilized, or simply that contact with nature would be insured. Ideally, decisions should reflect those considerations important to each individual.

For comparison, we will assume that both Mr. Leisure and Mr. Profit incur the same cost and receive the same price for each tree produced. The cost and price figures are those reported from Michigan by Rudolph (1972):

	*Cost**	*Price*
Scotch pine	$ .96	$2.95
White spruce	1.06	2.70
Douglas-fir	1.11	4.25

---

*Costs were compounded at 6 percent to the selling year.

The labor expended per tree grown and harvested was assumed to be constant for each grower but differed with species. Scotch pine required 45 minutes, white spruce 30 minutes, and Douglas-fir 40 minutes for the various production activities during an 8-year cycle.

Both growers want to use their land fully in growing Christmas trees, both will plant 1,200 trees per acre, and both will harvest all the trees at the end of 8 years.

While Mr. Leisure and Mr. Profit operate under virtually identical conditions, they have strongly contrasting personal interests. Mr. Leisure, a retired forester, grows trees as a hobby. His chief concern in growing trees is to occupy some of his idle time. Still, he wishes to commit no more than 3,200 hours of his time in one growing cycle. While hired labor is acceptable, Mr. Leisure prefers to hire as little as possible, and no more man-hours than he himself puts into the business. He prefers to grow trees of all three species (Douglas-fir, Scotch pine, white spruce), and does not want any one species to amount to fewer than 1,000 trees or more than 60 percent of the total planting. Further, he wants to limit his total investment to $10,000.

Mr. Profit is a self-employed economic consultant. Unlike Mr. Leisure, he is chiefly concerned with maximizing profits. He prefers to use hired labor for all production operations and there is no limit to the investment he is willing to make, provided there is a sufficient return for each dollar invested.

Results

The solutions obtained by GP for Mr. Leisure and Mr. Profit reflect the differences in their objectives (table 1). The solution for Mr. Profit was completely compatible with his limited objective. It suggested the obvious—plant 12,000 Douglas-fir to maximize profits. Since there were no restrictions on labor or investment, all 10 acres were fully utilized. Mr. Profit need not have turned to GP to solve his problem since, all the constraints were nonconflicting and all the goals were commensurate and easily achieved. A linear programing model or financial investment model would have provided Mr. Profit with an identical solution.

This is not true of the solution for Mr. Leisure. While satisfying most of his goals, he failed to achieve complete land utilization. The solution called for planting 2,771 Scotch pine, 1,000 white spruce, and 5,657 Douglas-fir, to meet the species requirements. An investment of $10,000 was required, just meeting the maximum allowed. And labor requirements were 29 hours below the 6,400-hour combined maximum. This solution netted a return of $24,919.

The solution might be satisfactory in actual practice, but it is also possible that using less than 80 percent of the available acreage would be unacceptable to Mr. Leisure. By reordering his original goal structure, Mr. Leisure can examine those alternatives that provide complete land utilization. All of them require compromise among some of the other goals previously established for his operation.

One obvious alternative that guarantees complete land use is that chosen by Mr. Profit—profit maximization. However, it would require a labor commitment that would exceed the goal level of 6,400 hours by 41 percent and an investment that would exceed the targeted amount of $10,000 by 33 percent. In addition, this solution called for the planting of only one species.

Table 1.—Initial goal programing solutions for Mr. Profit and Mr. Leisure

Item	Mr. Profit	Mr. Leisure
Investment	$13,320	$10,000
Acres	10.0	7.86
Net return	$37,680	$24,919
Scotch pine (no.)	0	2,771
White spruce (no.)	0	1,000
Douglas-fir (no.)	12,000	5,657
Labor: owner (man-hours)	0	3,200
Labor: hired (man-hours)	9,000	3,169

Table 2.—An alternative solution for Mr. Leisure providing complete land utilization

Item	Mr. Leisure
Investment	$12,678
Acres	10.0
Net return	$21,502
Scotch pine (number)	920
White spruce (number)	10,080
Douglas-fir (number)	1,000
Labor: owner (man-hours)	3,200
Labor: hired (man-hours)	3,200

Another alternative presented in table 2 provides for complete land use and still achieves some of the other goals Mr. Leisure selected. The total labor commitment is kept at 6,400 hours. It allows Mr. Leisure to grow trees of all three species, although not in the proportions prescribed. Unfortunately, the investment required still exceeds the prescribed amount by 27 percent while the net return is more than $3,400 less than that of the initial solution.

In actual practice it would now be up to Mr. Leisure to select among the alternative solutions presented or further restructure his goal priorities and/or levels to obtain other, more acceptable, solutions. GP cannot make the decision for Mr. Leisure, but it will allow him to investigate a variety of alternative solutions and choose among them objectively with clear recognition of the trade-offs and benefits involved.

DISCUSSION AND CONCLUSION

The decision problems presented in the example for Mr. Leisure and Mr. Profit were simplified. Costs were attached to trees produced and not to labor input. Labor was estimated and assigned to each tree produced, with no regard to its distribution within the 8-year cycle. The returns cited assume 100 percent survival and market acceptance.

Direct application of GP to specific operations, however, would require that various criteria be added to the model to allow for mixed length rotation, survival factors for the various species, seasonal and annual needs and availability of labor, and other criteria unique to a particular operation.

Because the example was hypothetical, problems inherent in GP (or, for that matter, any mathematical programing technique) were avoided. Bell (1975) cites several problems encountered by the Mt. Hood National Forest Planning Team in using GP to prescribe activities on the 93,000-acre Bull Run Planning Unit. Among these were: (1) specifying various goal levels, i.e., how many days of recreation, how many board feet of timber, etc.; (2) assigning priorities and weights within priorities to particular goals, i.e., what is more important? How much more? And to whom?; (3) development of input-output coefficients, i.e., how many days of recreation will result from varying management activities, etc.

The most critical of these three problems is development of the input-output coefficients. As seen in our example, priority ordering and even goal specification are often changed to reflect the decision maker's indecisiveness. In a sense, it is the resulting interaction between the decision maker and the model, caused by initial specification problems, that eventually allows the decision maker to define his final goal ordering and specification levels precisely and meaningfully.

Accuracy in developing input-output coefficients is essential, since it is these relationships that seek to duplicate the actual environment surrounding the decision. Should these be loosely conceived and inaccurate, the outcomes of the subsequent modeling might or might not be repeated in the real world. Imperfect information for developing the necessary coefficients must be allowed for by consciously weighing the risks involved.

The usefulness of goal programing to the Christmas tree industry goes far beyond the type of application illustrated. GP could help growers to develop and evaluate various marketing strategies and activities, on an individual or industrywide level. Individual growers may find GP helpful in developing an overall marketing strategy to guide decisions on price, market area selection, outlet, sales method, and other factors that relate directly to the total sales effort.

Industrywide applications might center on improving the overall effectiveness of the industry's promotional and public relations activities, including the selection of advertising media.

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Keywords: Christmas trees: goal programing

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Stand Development 25 Years after a 9.0-inch Diameter-Limit First Cutting in Appalachian Hardwoods

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ABSTRACT

This report is a case history of stand development 25 years after a 9.0-inch diameter-limit cutting in a primarily second growth 40- to 45-year-old Appalachian hardwood stand. Some old residual trees from the early 1900 logging era were scattered throughout the stand. In 1950, a 9.0-inch diameter-limit cutting removed 8,650 board feet per acre and reduced the basal area from 97 to 24 square feet per acre. Twenty-five years after this 1950 cutting, the total sawlog volume was 7,425 board feet per acre with a basal area of 98 square feet per acre. Oaks accounted for 42 percent of the sawlog-size trees and 45 percent of the sawlog stand volume.

THROUGHOUT THE Appalachian hardwood region, it is a common practice to harvest timber larger than a chosen diameter limit. Many foresters do not advocate this type of cutting because the larger trees are removed, so the stand is high-graded. Also trees below the diameter limit are not treated, so good and poor trees alike continue to grow. Hutnik (1958) indicated that foresters could recommend a diameter-limit cut as the initial cut, but that another type of cutting should be used thereafter.

We believe certain types of diameter-limit cutting or modifications of it have potential in Appalachian hardwood management, especially with the current concern for esthetics and environmental protection on forest lands. Such modifications could include a diameter-limit cut with a flexible cutting cycle, or a diameter-limit cut accompanied by improvement cutting or cultural treatment for trees below the minimum cutting diameter. No doubt there are others.

The purpose of this paper is to report a case history study of stand development 25 years after a 9.0-inch diameter-limit cut on a 40- to 45-year-old second growth Appalachian hardwood stand. Some old growth stems, residuals from the early 1900 logging period, were scattered throughout the stand.

We were also interested in the response of hardwood stems, particularly oaks, after partial cutting. (Scientific names of species are listed in the Appendix.) Scholz (1948) reported that 85- to 100-year-old sawtimber-size red oaks had a favorable diameter growth response after cutting. Likewise Minckler (1957) found that many 35- to 100-year-old pole-size white oak trees responded after release. Carvell (1969) reported similar results with diameter growth response for 40-year-old red oak on excellent sites; however, no response was evident on medium or low quality sites.

STUDY AREA

The study area is a 52-acre Appalachian hardwood stand located on the Fernow Experimental Forest near Parsons, West Virginia.

Annual precipitation averages about 58 inches with about 135 frost-free days. The red oak site index of the study area is 70, and the soils are Calvin channery silt loam about 30 inches deep.

The study area was cut (high-graded) between 1905 and 1910. In 1950, the area supported a sawtimber stand averaging 8,650 board feet per acre (International 1/4-inch rule, trees 11 inches dbh and greater); 1,725 board feet per acre of this volume was cull material, while old residuals totalled 3,000 board feet per acre. The basal area averaged 97 square feet per acre for all material 5.0 inches diameter at breast height (dbh) and larger.

METHODS

From May 1950 to March 1951, the study area was logged to a 9-inch diameter limit. All merchantable trees 9.0 inches dbh and larger were cut, and cull trees 9.0 inches dbh and larger were chemically frilled. The merchantable sawtimber removed amounted to 6,925 board feet per acre including about 3,000 from old-growth residual trees, plus 1,725 board feet per acre of cull. No cultural treatment was applied to cull trees less than 9.0 inches dbh. The residual stand consisted of trees that had previously been in the intermediate or overtopped crown class (fig. 1). About 31 percent of the total stems in the residual stand (5.0 inches or more dbh) were red, white, chestnut, or scarlet oaks (table

1). Residual basal area averaged 24 square feet per acre for trees 5.0 inches dbh and larger.

RESULTS

Twenty-five years later, the sawlog volume averaged 7,425 board feet per acre for trees 11.0 inches dbh and larger, including 100 board feet per acre of cull material. The merchantable volume was about 400 board feet per acre more than when the stand was cut in 1950 (table 2). The average volume growth was about 300 board feet per acre per year. Total stand basal area averaged 98 square feet per acre, which was similar to that in 1950 before cutting (table 2).

Figure 1.—Left: stand immediately after logging; right: stand development 25 years after logging.

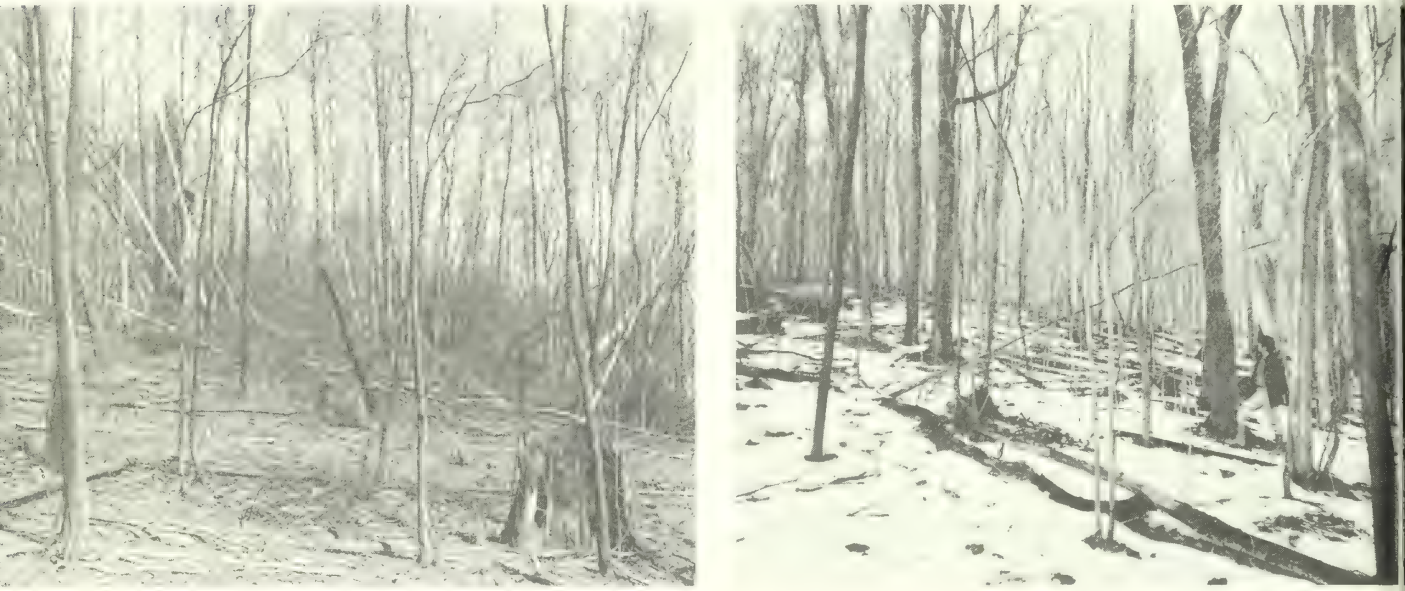

Table 1.—*Stand structure before and after 9-inch diameter-limit cutting*

Original stand - May 1950						Residual stand - March 1951		
Stems 5.0 to 10.9 inches dbh			Stems 11.0 plus inches dbh			Stems 5.0 to 9.0 inches dbh		
	Stem/acre	*Percent*		*Stem/acre*	*Percent*		*Stem/acre*	*Percent*
Red oak	21.4	15.1	Red oak	6.5	18.2	Red oak	15.5	14.1
Chestnut oak	17.7	12.5	Yellow-poplar	5.6	15.7	Chestnut oak	13.8	12.5
Black locust	16.4	11.6	Chestnut oak	4.1	11.5	Black locust	11.3	10.3
Sassafras	11.5	8.2	Sugar maple	3.8	10.7	Sassafras	10.1	9.2
Red maple	10.2	7.2	Hickory	2.6	7.3	Red maple	8.9	8.1
Yellow-poplar	9.8	6.9	Black cherry	2.6	7.3	Sweet birch	8.7	7.9
Sweet birch	9.7	6.9	Black locust	1.8	5.0	Yellow-poplar	6.3	5.7
White ash	6.0	4.2	Beech	1.7	4.8	Cucumbertree	4.7	4.3
Hickory	5.8	4.1	Scarlet oak	1.4	3.9	White ash	4.6	4.2
Cucumbertree	5.7	4.1	White oak	1.2	3.4	Hickory	4.6	4.2
Sugar maple	5.0	3.8	Black gum	1.0	2.8	Sugar maple	4.3	3.9
Black cherry	4.9	3.5	—	—	—	Black cherry	3.3	3.0
White oak	3.4	2.4	—	—	—	White oak	2.5	2.3
Scarlet oak	3.2	2.2	—	—	—	Scarlet oak	2.4	2.2
Beech	2.2	1.5	—	—	—	—	—	—
Others	8.4	5.8	Others	3.4	9.4	Others	8.9	8.1
Total	141.3			35.7			109.9	

Table 2.—*Initial, residual, and 1975 volume-basal area data*

Time period	Volume per acre [a]				Basal area per acre	
	Merch-antable	Cull	Merch-antable	Cull	Merch-antable	Cull
	Board feet		*Cubic feet*		*Square feet*	
Initial: before cutting (1950)	6,925	1,725	1,890	330	84	13
Residual: after cutting	0	0	385	0	24	0
25 years after cutting	7,325	100	2,230	40	96	2

[a] Board-foot volumes using International 1/4-inch log rule for trees 11.0 inches dbh to an 8.0 inch top dib. Cubic foot volumes for trees 5.0 inches dbh to a 4.0 inch top dib.

Table 3.—*Commercial reproduction in sapling-size stems 1.0 to 4.9 inches dbh before and after 25 years after cutting*

Before cutting			25 years after cutting		
Species	Stems per acre		Species	Stems per acre	
	Number	*Percent*		*Number*	*Percent*
Beech	198	37.0	Sugar maple	201	49.0
Sugar maple	121	22.6	Beech	61	14.8
Red maple	50	9.4	Sweet birch	34	8.3
Hickory	42	7.9	Red maple	24	5.8
Sweet birch	37	6.9	Yellow-poplar	20	4.9
Red oak	21	3.9	Red oak	12	2.9
White ash	14	2.6	Black cherry	10	2.4
Chestnut oak	13	2.4	Black locust	8	1.9
Others	39	7.3	Others	41	10.0
Total	535			411	

Table 4.—*Summary of pole-size and sawtimber stand structure 25 years after a 9-inch diameter-limit cutting (in number of stems per acre)*

Pole-size				Sawtimber-size					
Species	Dbh class (inches)			Species	Dbh class (inches)				
	5-8	9-10	Total		11-14	15-18	19-22	Over 22	Total
Black locust	11.8	3.0	14.8	Red oak	6.6	5.0	1.0	0.04	12.6
Red maple	9.9	4.0	13.9	Chestnut oak	6.2	.5			6.7
Sugar maple	10.1	3.0	13.1	Red maple	4.8	.6	.1		5.5
Yellow-poplar	10.0	2.6	12.6	Yellow-poplar	3.1	1.3	.1		4.5
Beech	9.2	1.3	10.5	Sugar maple	2.8	1.0	.1		3.9
Chestnut oak	6.0	4.0	10.0	Black locust	2.6	.2			2.8
Red oak	5.4	2.7	8.1	Black cherry	1.8	.7			2.5
Sweet birch	5.3	2.0	7.3	Cucumbertree	2.0	.3			2.3
Sassafras	3.9	2.3	6.2	Sweet birch	1.5				1.5
Hickory	4.4	1.6	6.0	White ash	1.2	.2			1.4
Cucumbertree	3.6	1.4	5.0	White oak	1.0	.3			1.3
Black cherry	3.1	1.4	4.5	Sassafras	1.2				1.2
White ash	3.0	1.2	4.2	Hickory	1.1				1.1
White oak	2.2	.9	3.1	Beech	.7				.7
Others	10.5	1.6	12.1	Others	.9				.9
Total	98.4	33.0	131.4	Total	37.5	10.1	1.3	0.04	48.9

The present stand is a vigorous young sawtimber-size stand with little defect. Approximately 42 percent of the sawtimber volume consists of red, white, and chestnut oaks. Details of the current structure are summarized in table 4.

Sapling-size reproduction in stems 1.0 to 4.9 inches dbh was tallied before cutting and 25 years later (table 3). Before cutting, beech and sugar maple dominated the reproduction, totaling about 60 percent of the commercial saplings. After 25 years, about 64 percent of the commercial saplings were sugar maple and beech. Before cutting, beech was the more prominent species, but 25 years after cutting sugar maple was more abundant.

DISCUSSION AND CONCLUSIONS

In 1975, the most striking aspect of the new stand was the abundance of well-formed, fast-growing oaks. Oaks accounted for 42 percent of the sawlog-size trees, and 45 percent of the sawlog stand volume. Most of the stems were free from superficial defect.

One cannot base general silvicultural recommendations on a single case study, but this area supported a well developed young sawtimber stand, most of which probably developed from the pole-size material left after the logging.

Perhaps the most significant point in this paper is the response of these residual pole-size stems and large saplings. Currently, many foresters recommend the cutting or killing of all woody stems 1.0 inch in diameter (dbh) and larger during clearcutting. In many cases, they are justified in making this recommendation because small stems can overtop certain young seedlings and seriously influence their stem development. However, there are situations where the landowner should use discretion in cutting all stems 1.0 inch dbh and larger.

In the future, we should be alert for situations where vigorous pole-size stems have a good chance to respond after the removal of the overstory. We do suggest caution, however, for some older stands may not respond as the stand in this study did, though oak stands seem to respond well (Scholz 1948, Minckler 1957). Documenting of other situations is necessary to establish better guidelines.

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APPENDIX

Common and scientific names of species referred to in this study:

Ash, white	*Fraxinus americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Cherry, black	*Prunus serotina* Ehrh.
Cucumbertree	*Magnolia acuminata* L.
Gum, black	*Nyssa sylvatica* Marsh.
Hickory	*Carya* spp.
Locust, black	*Robinia pseudoacacia* L.
Maple, red	*Acer rubrum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Oak, scarlet	*Quercus coccinea* Muenchh.
Oak, white	*Quercus alba* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Yellow-poplar	*Liriodendron tulipifera* L.

Smith, H. Clay, and N. I. Lamson.
1977. **Stand development 25 years after a 9.0-inch diameter-limit first cutting in Appalachian hardwoods.** Northeast. For. Exp. Stn., Upper Darby, Pa.
4 p., illus. (U.S. Dep. Agric., For. Serv. Res. Pap. NE-379)

This report is a case history of stand development 25 years after a 9.0-inch diameter-limit cutting in a primarily second growth 40- to 45-year-old Appalachian hardwood stand. Some old residual trees from the early 1900 logging era were scattered throughout the stand. In 1950, a 9.0-inch diameter-limit cutting removed 8,650 board feet per acre and reduced the basal area from 97 to 24 square feet per acre. Twenty-five years later, the total sawlog volume was 7,425 board feet per acre with a basal area of 98 square feet per acre. Oaks accounted for 42 percent of the sawlog-size trees and 45 percent of the sawlog stand volume.

Keywords: Diameter limit, stand development, Appalachian hardwoods, *Quercus* spp.
221.4:181.65:228:176.1 *Quercus*

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Predicted Cubic-foot Yields of Lumber, Sawdust, and Sawmill Residue from the Sawtimber Portions of Hardwood Trees

GOVT. DOCUMENTS
DEPOSITORY ITEM

by Leland F. Hanks

FOREST SERVICE RESEARCH PAPER NE-380
1977

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ABSTRACT

We have presented prediction equations and tables for estimating the gross cubic-foot volume of sawtimber for hardwood trees, and cubic-foot yields of lumber, sawdust, and sawmill residue that are produced during the sawing process. Yields are presented for northern red oak, black oak, white oak, chestnut oak, red maple, sugar maple, yellow-poplar, yellow birch, paper birch, and basswood.

Predicted Cubic-foot Yields of Lumber, Sawdust, and Sawmill Residue from the Sawtimber Portions of Hardwood Trees

SINCE THE TURN of the century, much has been written about the board foot versus the cubic foot as the standard measure for tree volume. Now, after many years, the cubic-foot measure is being viewed more favorably.

The board-foot measure has been used for trees that are sawed into lumber, and this practice will continue for some time. But, if lumber volume is measured in board feet, why not use the same unit for measuring log and tree volumes? On the surface this may appear reasonable, but utilization practices have changed; the multiproduct tree is now on the scene. Veneer, chips, sawdust, and, of course, lumber, are all being marketed from the same tree. And each of these products requires a separate unit of measure.

Initially we have to account for the total wood content of a tree; this requires a unit of measure that can be used without regard for the product that is marketed from that tree. The cubic foot is such a measure, and cubic-foot tree volume can be related meaningfully to any end product.

The cubic-foot volumes of end products in this paper represent the output of several sawmills. The trees that were processed through the mills varied in size, straightness, and interior defect; the mills' cutting schedules also varied. Therefore we are not presenting case histories for specific sawmills and the surrounding timber, but species averages that will be useful to timber sellers and buyers.

SAMPLE

The trees used for this study were selected in groups of about 50 at 45 locations in 16 states (figs. 1-10). We measured the diameter at breast height (dbh) on standing trees, and measured the merchantable height after the trees were felled. The merchantable height included all logs that qualified as local use or better.[1] Inside bark diameter at each end of a log was measured to the nearest 0.1 inch, and length was measured to the nearest 0.1 foot. Log lengths ranged from 8 to 16 feet, and averaged about 12 feet. The logs were sawed, and nominal green board widths, lengths, and thicknesses were recorded for all lumber that was produced from the sawing. Ninety-five percent of the lumber volume was sawed in thicknesses of 4/4, 5/4, 6/4, and 8/4 inch. We numbered the logs and boards so that all boards from a tree could be identified.

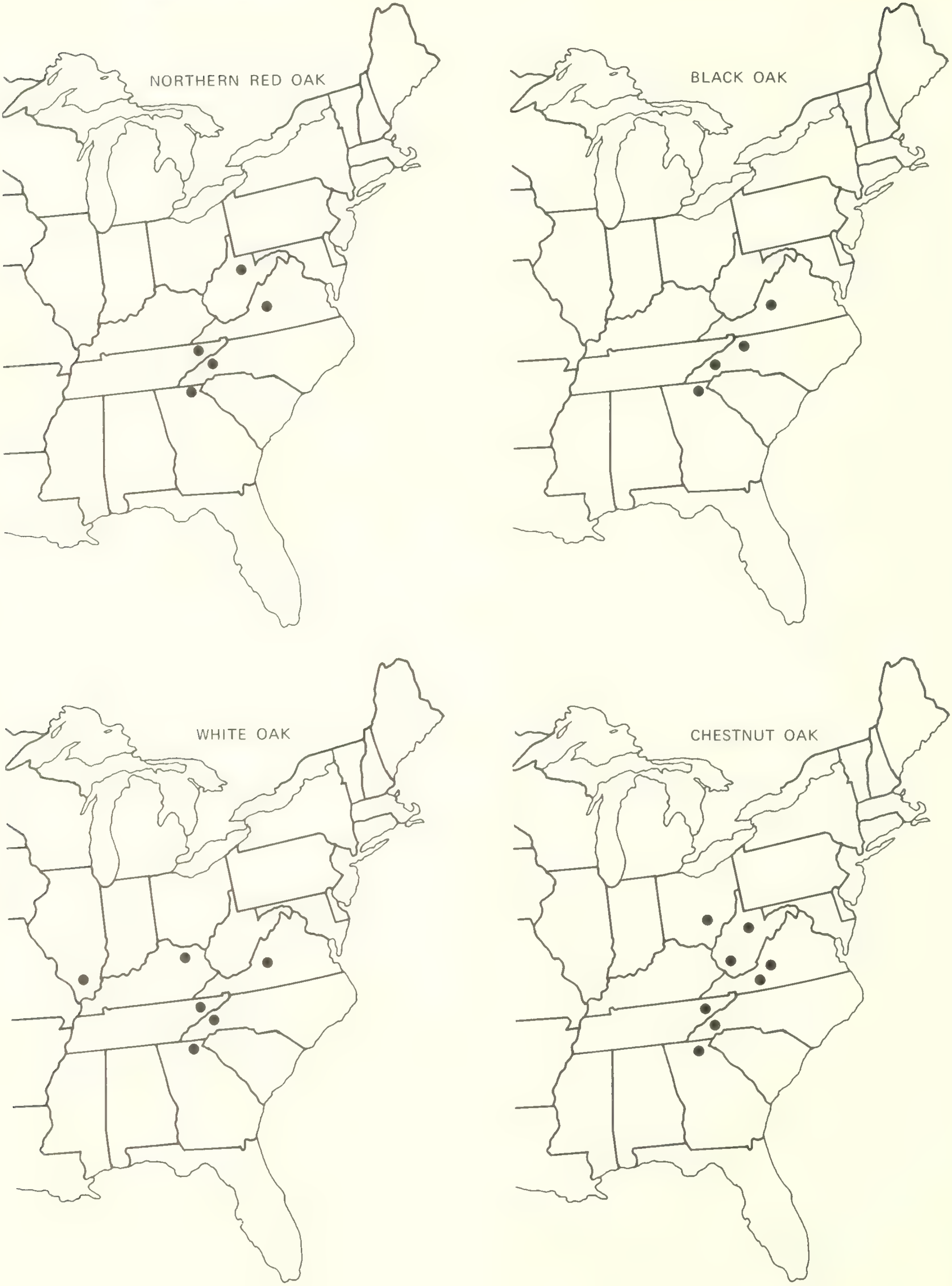
For each of the 10 species that we studied, data were separated by trees that were sawed at band mills and those sawed at circular mills. Because we required a minimum sample of 100 trees for inclusion in the analysis, our investigation at circular mills was limited to red maple, yellow-poplar, yellow birch, and paper birch.

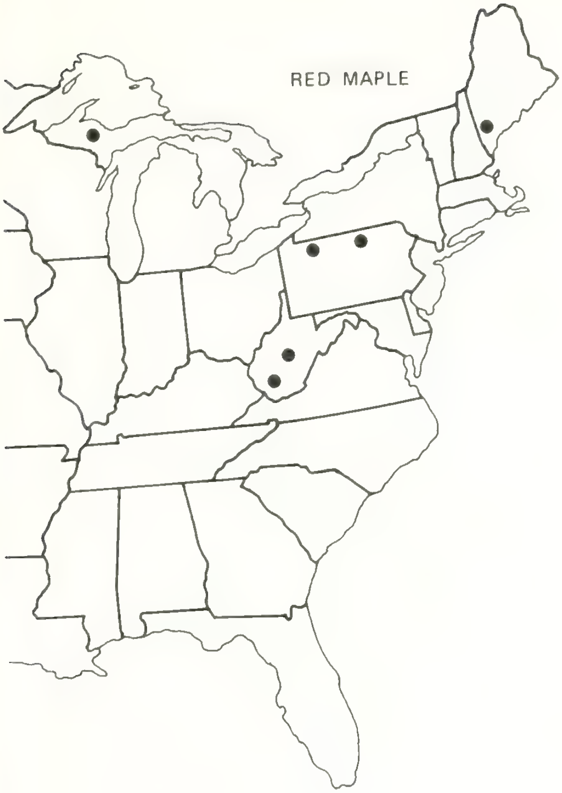
A total of 1,802 trees from all species were sawed at band mills; 790 trees were sawed at cir-

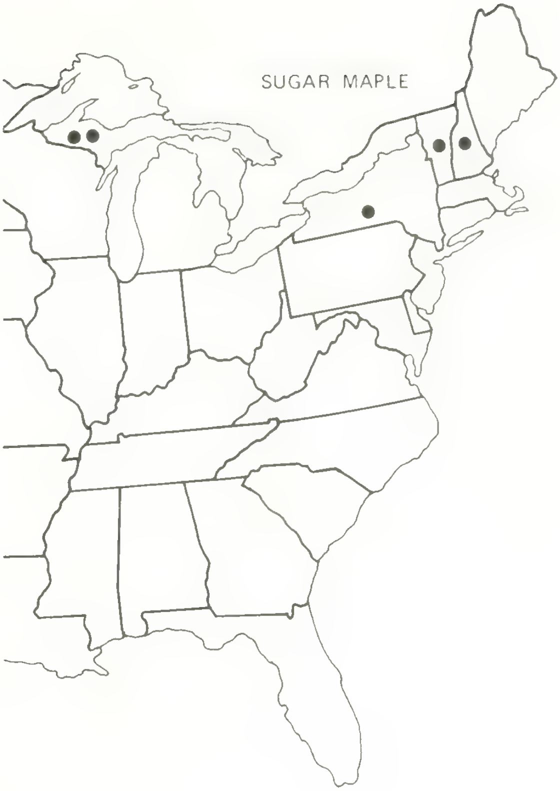
---

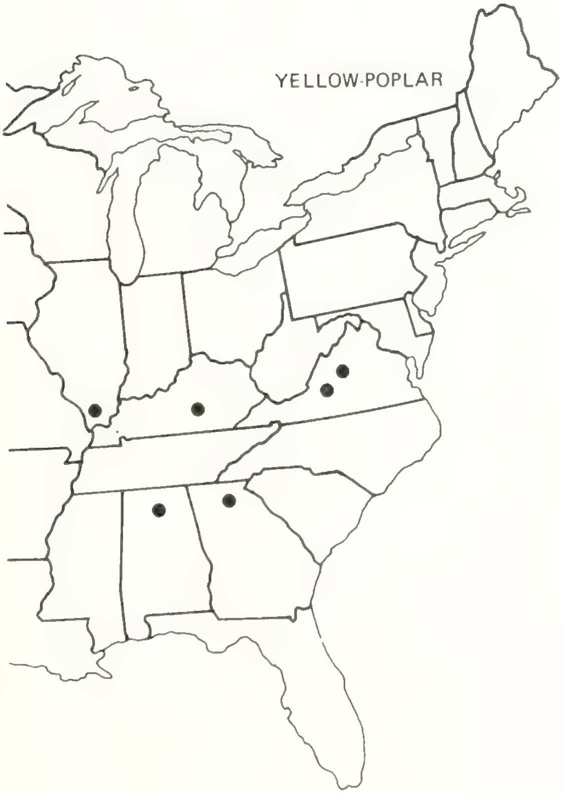
[1] A local-use class log must scale at least 8 inches in diameter inside bark (dib) by 8 feet long, and it must be one-third sound.

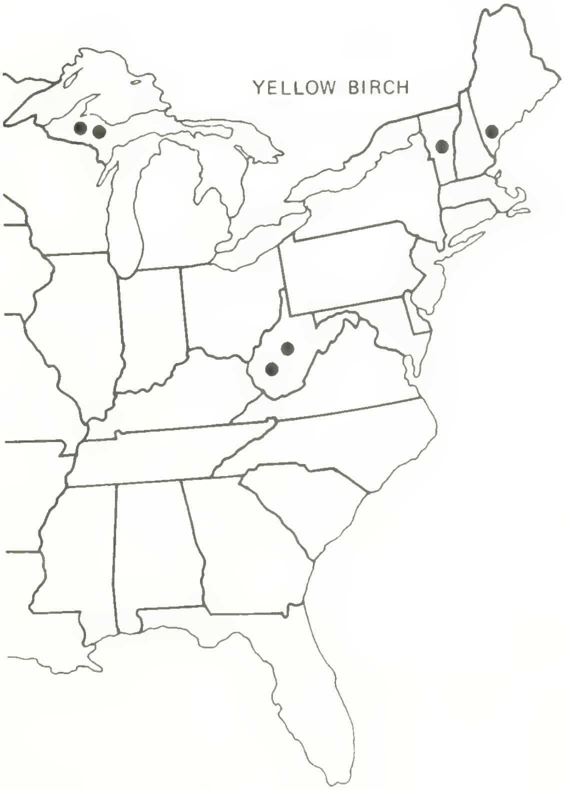
Figures 1-10.—Location of general areas where sample trees for each species were cut.

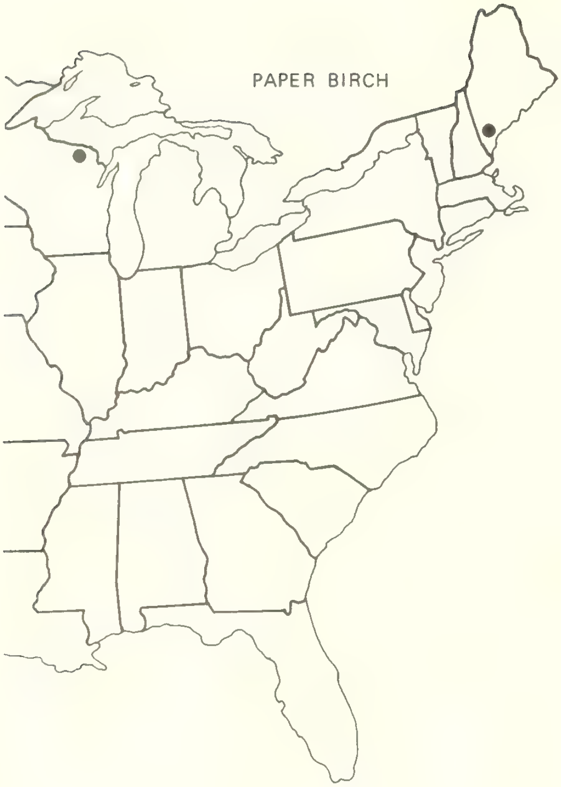


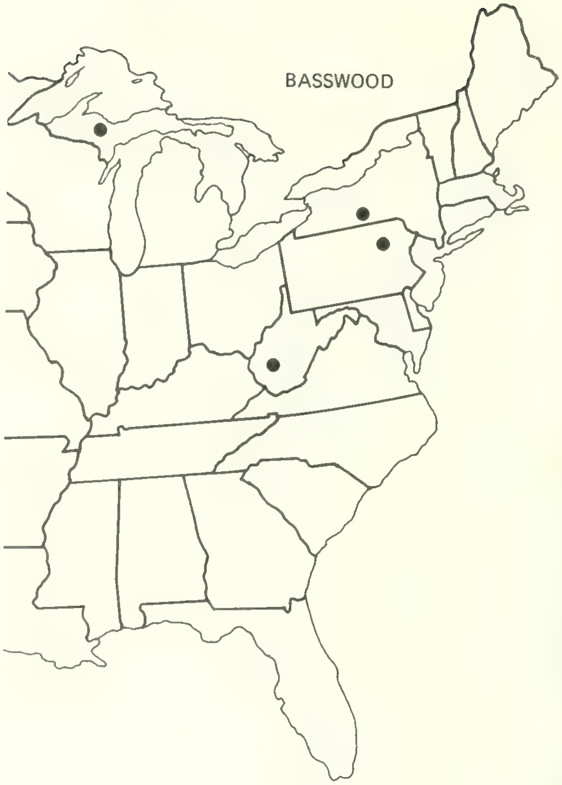

RED MAPLE


SUGAR MAPLE


YELLOW-POPLAR


YELLOW BIRCH





cular mills. Because of the 100-tree minimum, 242 of the trees that were sawed at circular mills were available only for calculating the gross tree volumes and the sawmill residue volumes (table 1).

DEPENDENT VARIABLES

Gross Tree Volume

Gross tree volume is the volume inside bark from the top of the stump to the top of the last sawlog. To calculate the actual gross tree volume, we added the cubic-foot volumes for all bucked sections, using this equation:

$$\text{Sectional cubic-foot volume} = .001818\,(D^2+Dd+d^2)\,L$$

D = inside bark diameter of large end
d = inside bark diameter of small end
L = log length

This equation produces the volume for a conoid, and has been used extensively for estimating the cubic-foot volume for logs. Because of butt-flare, the first log was divided at breast height, and volumes were determined for each section.

We used the equation to compute the cubic-foot volume of sawlogs for five groups of trees. We compared these volumes with those that were computed from measurements obtained with a Barr and Stroud dendrometer, a very accurate measuring device.[2]

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[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute endorsement or approval by the Forest Service or the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

Species	*Number of trees*	*Dendrometer*	*Equation*	*Percent difference*
		*ft*³		
Black oak	43	2,752	2,755	+0.1
White oak	88	4,382	4,350	−0.7
Yellow-poplar	66	4,278	4,313	+0.8
Yellow-poplar	53	3,749	3,713	−1.0
Basswood	45	1,988	1,965	−1.2

The closeness of the sawlog volumes for each tree group indicates that our equation provides a good base from which to work.

Lumber Volume

Lumber volume is the cubic-foot volume of green lumber that is produced during the sawing of all sawlogs from a tree. We did not measure the actual dimensions of the lumber sawed from study trees; instead, we recorded nominal sizes and adjusted them to industry averages. These averages were then used to estimate cubic-foot volume. To determine the industry averages, we visited several mills and measured actual sizes of green lumber; other research groups provided similar data. As expected, the actual width of rough hardwood boards is random; this means that the industry average width of boards in the 7-inch class is 7.0 inches. We found that the industry practice for trimming hardwood lumber is to leave 2 inches of trim beyond the nominal length. Therefore we added 2 inches to the nominal length of every board.

It was more difficult to determine the industry average thickness for each thickness class because the thickness for each class varied within and between mills. The average thicknesses that we used for the nominal thicknesses of lumber were:

Nominal thickness (inches)	*Average thickness (inches)*
3/8	0.45
2/4	.60
5/8	.70
3/4	.90
4/4	1.15
5/4	1.40
6/4	1.65
7/4	1.95
8/4	2.20
9/4	2.50
10/4	2.70
3-10[3]	nominal

Therefore, the cubic-foot volume of each board that is sawed from the study trees is the product of nominal width, nominal length plus 2 inches, and average thickness.

Sawdust Volume

Sawdust volume is the cubic-foot volume of solid wood that was converted to sawdust during the sawing of all sawlogs from a tree. The sawdust volume equals the kerf multiplied by the sum of the area that is included in both edges and one surface of each board. We used kerfs of 17/64 and 10/64 for lumber sawed at circular and band mills, respectively.

Sawmill Residue Volume

Sawmill residue volume is the cubic-foot volume of a tree-including rot and voids—that reaches the mill and is not converted to lumber or sawdust. We calculated this volume for each tree by subtracting the cubic-foot volumes of lumber and sawdust from the gross cubic-foot volume of sawlog material.

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[3] A small amount of timber and sound square-edge material was sawed in these sizes; when sawed properly, this material was sized to nominal thickness.

Table 1.—*Regression coefficients and statistics for 10 species of hardwoods*

Volume of:	Independent variables				Number of trees	SE	R²	Means		
	Constant	Dbh²	Merchantable height	Dbh² x Merchantable height				Dbh	Merchantable height	Volume
						ft³		*in*	*ft*	*ft³*
				NORTHERN RED OAK						
Sawtimber (gross)	-0.3881	0.039417	0.0868	0.002328	207	7.3	0.97	23.8	41.6	85.9
Lumber (band)	4.8744	.003100	-.2392	.002262	207	8.6	.93	23.8	41.6	54.5
Sawdust (band)	.5149	.000982	-.0075	.000305	207	1.1	.94	23.8	41.6	8.6
Sawmill residue	-7.3598	.034009	.3933	-.000283	207	6.9	.49	23.8	41.6	21.9
				WHITE OAK						
Sawtimber (gross)	-5.3835	.054092	.1215	.002184	369	5.6	.98	19.7	38.0	57.3
Lumber (band)	1.3601	.023486	-.1751	.001814	304	6.9	.93	20.1	40.2	36.9
Sawdust (band)	-.3244	.004662	.0017	.000240	304	1.0	.93	20.1	40.2	6.0
Sawmill residue	-8.6249	.032797	.3701	-.000106	369	5.5	.67	19.7	38.0	17.2
				BLACK OAK						
Sawtimber (gross)	2.0988	.034454	-.0597	.002662	224	7.1	.97	20.6	40.4	67.4
Lumber (band)	-.5110	.021918	-.0877	.001851	182	6.6	.95	20.7	41.3	42.9
Sawdust (band)	-.5027	.003953	.0106	.000239	182	1.0	.95	20.7	41.3	6.5
Sawmill residue	3.1353	.009322	.0048	.000553	224	4.6	.80	20.6	40.4	18.4
				CHESTNUT OAK						
Sawtimber (gross)	1.2038	.030685	-.0533	.002628	325	4.9	.98	19.3	34.8	49.0
Lumber (band)	8.5231	-.004667	-.3550	.002418	278	6.3	.94	19.6	35.0	30.3
Sawdust (band)	.8519	.000404	-.0262	.000326	278	.9	.95	19.6	35.0	5.0
Sawmill residue	-5.9021	.025836	.2844	.000033	325	3.9	.77	19.3	34.8	14.7
				RED MAPLE						
Sawtimber (gross)	-8.2716	.067257	.2919	.001582	290	4.5	0.96	16.8	37.7	41.6
Lumber										
band	-3.3243	.038318	.0645	.001239	148	2.8	.93	15.4	35.8	19.8
circular	-6.6517	.033630	.1033	.001199	131	5.1	.91	18.0	39.9	26.1
Sawdust										
band	-.8697	.007539	.0363	.000116	148	.4	.94	15.4	35.8	3.4
circular	-1.5823	.008581	.0323	.000344	131	1.5	.91	18.0	39.9	7.5
Sawmill residue	-6.5433	.043444	.2590	-.000293	290	3.8	.66	16.8	37.7	12.7
				SUGAR MAPLE						
Sawtimber (gross)	-3.0969	.047412	.1522	.001972	302	4.4	.98	19.9	36.0	53.6
Lumber (band)	-.9914	.022793	.0712	.001209	247	5.6	.90	20.0	35.0	30.2
Sawdust (band)	.0855	.002969	.0165	.000173	247	.7	.91	20.0	35.0	4.6
Sawmill residue	-2.8548	.027218	.0848	.000343	302	5.2	.74	19.9	36.0	17.0

				YELLOW-POPLAR						
Sawtimber (gross)	2.1321	.041200	-.0853	.002540	334	5.6	.97	19.4	49.8	65.5
Lumber										
band	.0437	.036323	-.1723	.001789	164	5.8	.94	19.2	48.7	40.2
circular	-.4148	.026306	-.0905	.001659	170	4.7	.95	19.6	50.9	40.6
Sawdust										
band	.0807	.004333	-.0174	.000303	164	1.0	.94	19.2	48.7	6.8
circular	-.0939	.005563	-.0078	.000484	170	1.3	.95	19.6	50.9	12.0
Sawmill residue	1.1260	.006653	.1015	.000318	334	4.4	.60	19.4	49.8	15.2
				PAPER BIRCH						
Sawtimber (gross)	1.0228	.031134	.0240	.002639	107	2.2	.96	15.5	32.9	30.7
Lumber (circular)	.9502	.011203	-.0476	.001575	107	2.2	.86	15.5	32.9	14.8
Sawdust (circular)	.2882	.002978	-.0035	.000469	107	.6	.87	15.5	32.9	4.7
Sawmill residue	-.2709	.016963	.0771	.000590	107	2.2	.69	15.5	32.9	11.2
				YELLOW BIRCH						
Sawtimber (gross)	-.6746	.042149	.0480	.002116	289	4.0	.98	18.4	32.9	42.7
Lumber										
band	1.2459	.014880	-.1192	.001693	149	5.1	.94	19.0	34.0	26.4
circular	-2.9289	.028893	.0518	.001075	140	3.3	.93	17.8	31.8	20.4
Sawdust										
band	.6902	.000377	-.0271	.000328	149	1.0	.92	19.0	34.0	4.5
circular	-.2540	.005756	.0183	.000344	140	1.0	.92	17.8	31.8	6.1
Sawmill residue	-.5104	.016796	.1118	.000344	289	4.4	.70	18.4	32.9	13.4
				BASSWOOD						
Sawtimber (gross)	-11.6496	.076817	.3247	.001426	145	3.8	.97	16.6	43.4	43.2
Lumber (band)	-9.6836	.044338	.2508	.000819	123	4.9	.89	16.7	43.0	24.8
Sawdust (band)	-1.9536	.007502	.0572	.000129	123	.8	.89	16.7	43.0	4.4
Sawmill residue	2.1330	.015172	-.0364	.000638	145	3.4	.78	16.6	43.4	13.3

RESULTS

Prediction Equations

For each species and dependent variable, standard regression procedures were used to calculate equations of the following form:

$$\text{cubic-foot volume} = a + b\,(\text{dbh})^2 + c\,(\text{merchantable height}) + d\,(\text{dbh}^2 \times \text{merchantable height}).$$

Cubic-foot regression coefficients and related data are shown in table 1.

Gross tree volumes and sawmill residue volumes are not affected by kerf size, so all trees were used when these variables were investigated. However, kerf size does influence lumber and sawdust volumes, so the equations for these variables are identified by type of headsaw.

Cubic-foot tables

For each species, the prediction equations were solved for various size classes, and the cubic-foot volumes of sawmill products were obtained by band or circular mills, or both (tables 2-14). The boxed area in each table indicates the size classes that were included in our sample trees. Differences between gross tree volume and the sum of lumber, sawdust, and sawmill residue volumes may be attributed to cull sections within the merchantable stem that were bucked out and left in the woods. The volumes that are outside of the boxed areas should be used with caution.

DISCUSSION

Gross Tree Volume

Gross tree volumes are of interest to those who purchase and sell timber on a cubic-foot basis. From the predicted gross cubic-foot volumes we learned that differences in volume between species were often small. To test whether these differences were significant, we conducted F-tests on the residual mean squares. The results indicated that there were significant differences between species, so we have included separate equations and tables for each species. If a user does not feel that the differences between species are meaningful, he may combine two or more species and create a composite table for gross cubic-foot volume.

Lumber Volume

For three species we tabulated cubic-foot lumber volumes for both band and circular mills. We expected the band mills to produce greater volumes of lumber than the circular mills; this was true for red maple in every tree size. However the small yellow-poplar and yellow birch trees that were processed through circular mills yielded more lumber than did comparable trees processed through band mills. This can happen for many reasons, but an inspection of the log scales showed that the band mills yielded less lumber from these two species because of a large amount of scalable defect in several logs that were sawed at these mills. Defect in the trees was not considered in the equations because the benefits gained would not offset the difficulties encountered in estimating the defect.

When using the predicted cubic-foot volumes of lumber for small yellow-poplar and yellow birch trees, one should be aware of the inconsistency between volumes for band and circular mills. Use the circular mill volumes as is; use the band mill volumes as is, or adjust them upward to circular mill volumes.

Sawdust Volume

Sawdust volume is directly related to kerf size. For a kerf size that differs from the size that we used (band: 10/64; circular: 17/64), an adjusted sawdust volume can be determined by this equation:

$$\begin{matrix}\text{Adjusted}\\ \text{sawdust}\\ \text{volume}\end{matrix} = \begin{matrix}\text{Published}\\ \text{sawdust}\\ \text{volume}\end{matrix} \times \frac{\text{new kerf}}{10/64 \text{ or } 17/64}$$

To adjust the sawdust volumes for red maple, yellow-poplar, or yellow birch, select the kerf that is closest to what your mill is using. The sawdust volumes that are derived for that kerf are the volumes that you will adjust.

TEXT CONTINUES ON PAGE 22.

TABLE 2.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM NORTHERN RED OAK BY BAND MILLS (CUBIC FEET)

		MERCHANTABLE HEIGHT (FEET)						
DBH (INCHES)	PRODUCT	24	32	40	48	56	64	72
10	LUMBER	4.9	4.8	4.7	4.6	4.5	4.4	4.2
	SAWDUST	1.2	1.3	1.5	1.7	1.9	2.1	2.3
	RESIDUE	4.8	7.7	10.6	13.6	16.5	19.4	22.3
	GROSS TREE	11.2	13.8	16.3	18.9	21.5	24.0	26.6
11	LUMBER	6.1	6.4	6.6	6.9	7.2	7.5	7.7
	SAWDUST	1.3	1.6	1.8	2.0	2.3	2.5	2.8
	RESIDUE	5.4	8.2	11.1	14.0	16.9	19.7	22.6
	GROSS TREE	13.2	16.2	19.1	22.1	25.0	28.0	30.9
12	LUMBER	7.4	8.1	8.8	9.5	10.2	10.9	11.6
	SAWDUST	1.5	1.8	2.1	2.4	2.7	3.0	3.3
	RESIDUE	6.0	8.8	11.6	14.5	17.3	20.1	22.9
	GROSS TREE	15.4	18.8	22.2	25.5	28.9	32.3	35.7
13	LUMBER	8.8	10.0	11.1	12.3	13.4	14.6	15.7
	SAWDUST	1.7	2.1	2.4	2.8	3.1	3.5	3.9
	RESIDUE	6.7	9.4	12.2	15.0	17.7	20.5	23.3
	GROSS TREE	17.8	21.6	25.5	29.3	33.2	37.0	40.9
14	LUMBER	10.4	12.0	13.6	15.3	16.9	18.5	20.2
	SAWDUST	2.0	2.4	2.8	3.2	3.6	4.1	4.5
	RESIDUE	7.4	10.1	12.8	15.5	18.2	20.9	23.6
	GROSS TREE	20.4	24.7	29.1	33.4	37.8	42.1	46.4
15	LUMBER	12.0	14.2	16.4	18.5	20.7	22.8	25.0
	SAWDUST	2.2	2.7	3.2	3.7	4.2	4.6	5.1
	RESIDUE	8.2	10.8	13.5	16.1	18.8	21.4	24.0
	GROSS TREE	23.1	28.0	32.9	37.8	42.7	47.6	52.4
16	LUMBER	13.8	16.5	19.3	22.0	24.7	27.4	30.1
	SAWDUST	2.5	3.0	3.6	4.2	4.7	5.3	5.8
	RESIDUE	9.0	11.6	14.2	16.7	19.3	21.9	24.4
	GROSS TREE	26.1	31.6	37.0	42.5	47.9	53.4	58.9
17	LUMBER	15.7	19.0	22.4	25.7	29.0	32.3	35.6
	SAWDUST	2.7	3.4	4.0	4.7	5.3	6.0	6.6
	RESIDUE	9.9	12.4	14.9	17.4	19.9	22.4	24.9
	GROSS TREE	29.2	35.3	41.4	47.5	53.5	59.6	65.7
18	LUMBER	17.7	21.7	25.6	29.6	33.5	37.5	41.4
	SAWDUST	3.0	3.8	4.5	5.2	5.9	6.7	7.4
	RESIDUE	10.9	13.3	15.7	18.1	20.5	23.0	25.4
	GROSS TREE	32.6	39.3	46.0	52.8	59.5	66.2	72.9
19	LUMBER	19.9	24.5	29.1	33.7	38.3	42.9	47.6
	SAWDUST	3.3	4.2	5.0	5.8	6.6	7.4	8.3
	RESIDUE	11.9	14.2	16.6	18.9	21.2	23.6	25.9
	GROSS TREE	36.1	43.5	50.9	58.3	65.8	73.2	80.6
20	LUMBER	22.1	27.4	32.7	38.1	43.4	48.7	54.0
	SAWDUST	3.7	4.6	5.5	6.4	7.3	8.2	9.2
	RESIDUE	13.0	15.2	17.4	19.7	21.9	24.2	26.4
	GROSS TREE	39.8	48.0	56.1	64.2	72.4	80.5	88.7
21	LUMBER	24.4	30.5	36.6	42.6	48.7	54.8	60.8
	SAWDUST	4.0	5.0	6.0	7.0	8.1	9.1	10.1
	RESIDUE	14.1	16.2	18.4	20.5	22.7	24.8	27.0
	GROSS TREE	43.7	52.6	61.5	70.4	79.3	88.3	97.2
22	LUMBER	26.9	33.8	40.6	47.4	54.3	61.1	68.0
	SAWDUST	4.4	5.5	6.6	7.7	8.8	10.0	11.1
	RESIDUE	15.3	17.3	19.4	21.4	23.5	25.5	27.6
	GROSS TREE	47.8	57.5	67.2	76.9	86.6	96.4	106.1
23	LUMBER	29.5	37.2	44.8	52.5	60.1	67.8	75.4
	SAWDUST	4.7	6.0	7.2	8.4	9.6	10.9	12.1
	RESIDUE	16.5	18.4	20.4	22.3	24.3	26.2	28.2
	GROSS TREE	52.1	62.6	73.2	83.7	94.3	104.8	115.4
24	LUMBER	32.2	40.7	49.2	57.7	66.2	74.7	83.2
	SAWDUST	5.1	6.5	7.8	9.2	10.5	11.8	13.2
	RESIDUE	17.8	19.6	21.4	23.3	25.1	27.0	28.8
	GROSS TREE	56.6	68.0	79.4	90.8	102.3	113.7	125.1
25	LUMBER	35.0	44.4	53.8	63.2	72.6	82.0	91.4
	SAWDUST	5.5	7.0	8.5	9.9	11.4	12.8	14.3
	RESIDUE	19.1	20.8	22.6	24.3	26.0	27.7	29.5
	GROSS TREE	61.3	73.6	85.9	98.3	110.6	122.9	135.3
26	LUMBER	37.9	48.2	58.6	68.9	79.2	89.5	99.8
	SAWDUST	5.9	7.5	9.1	10.7	12.3	13.9	15.5
	RESIDUE	20.5	22.1	23.7	25.3	26.9	28.6	30.2
	GROSS TREE	66.1	79.4	92.7	106.0	119.2	132.5	145.8
27	LUMBER	41.0	52.2	63.5	74.8	86.1	97.4	108.6
	SAWDUST	6.4	8.1	9.8	11.5	13.3	15.0	16.7
	RESIDUE	21.9	23.4	24.9	26.4	27.9	29.4	30.9
	GROSS TREE	71.2	85.4	99.7	114.0	128.2	142.5	156.8
28	LUMBER	44.1	56.4	68.7	80.9	93.2	105.5	117.8
	SAWDUST	6.8	8.7	10.5	12.4	14.3	16.1	18.0
	RESIDUE	23.4	24.8	26.2	27.5	28.9	30.3	31.6
	GROSS TREE	76.4	91.7	107.0	122.3	137.6	152.9	168.2
29	LUMBER	47.4	60.7	74.0	87.3	100.6	113.9	127.2
	SAWDUST	7.3	9.3	11.3	13.3	15.3	17.3	19.3
	RESIDUE	25.0	26.2	27.5	28.7	29.9	31.2	32.4
	GROSS TREE	81.8	98.2	114.5	130.9	147.3	163.6	180.0
30	LUMBER	50.8	65.2	79.5	93.9	108.3	122.6	137.0
	SAWDUST	7.8	9.9	12.1	14.2	16.4	18.5	20.6
	RESIDUE	26.6	27.7	28.8	29.9	31.0	32.1	33.2
	GROSS TREE	87.5	104.9	122.4	139.8	157.3	174.7	192.2

TABLE 3.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM WHITE OAK BY BAND MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET)						
		24	32	40	48	56	64	72
10	LUMBER	3.9	3.9	4.0	4.0	4.1	4.1	4.2
	SAWDUST	0.8	1.0	1.2	1.4	1.6	1.8	2.0
	RESIDUE	3.3	6.2	9.0	11.9	14.8	17.7	20.5
	GROSS TREE	8.2	10.9	13.6	16.3	19.1	21.8	24.5
11	LUMBER	5.3	5.6	6.0	6.3	6.7	7.0	7.4
	SAWDUST	1.0	1.2	1.5	1.7	2.0	2.2	2.5
	RESIDUE	3.9	6.8	9.6	12.5	15.4	18.2	21.1
	GROSS TREE	10.4	13.5	16.6	19.7	22.8	25.9	28.9
12	LUMBER	6.8	7.5	8.2	8.9	9.6	10.3	10.9
	SAWDUST	1.2	1.5	1.8	2.1	2.4	2.7	3.0
	RESIDUE	4.6	7.5	10.3	13.1	16.0	18.8	21.6
	GROSS TREE	12.9	16.4	19.8	23.3	26.8	30.3	33.8
13	LUMBER	8.5	9.5	10.6	11.6	12.7	13.7	14.8
	SAWDUST	1.5	1.8	2.2	2.5	2.8	3.2	3.5
	RESIDUE	5.4	8.2	11.0	13.8	16.6	19.5	22.3
	GROSS TREE	15.5	19.5	23.4	27.3	31.2	35.2	39.1
14	LUMBER	10.3	11.7	13.2	14.6	16.1	17.5	19.0
	SAWDUST	1.8	2.1	2.5	2.9	3.3	3.7	4.1
	RESIDUE	6.2	9.0	11.8	14.6	17.4	20.2	23.0
	GROSS TREE	18.4	22.8	27.2	31.6	36.0	40.4	44.8
15	LUMBER	12.2	14.1	16.0	17.8	19.7	21.6	23.4
	SAWDUST	2.1	2.5	3.0	3.4	3.8	4.3	4.7
	RESIDUE	7.1	9.8	12.6	15.4	18.1	20.9	23.7
	GROSS TREE	21.5	26.4	31.3	36.2	41.1	46.0	50.9
16	LUMBER	14.3	16.6	18.9	21.3	23.6	25.9	28.2
	SAWDUST	2.4	2.9	3.4	3.9	4.4	4.9	5.4
	RESIDUE	8.0	10.7	13.5	16.2	19.0	21.7	24.5
	GROSS TREE	24.8	30.2	35.7	41.1	46.6	52.0	57.5
17	LUMBER	16.5	19.3	22.1	24.9	27.7	30.5	33.3
	SAWDUST	2.7	3.3	3.9	4.4	5.0	5.6	6.1
	RESIDUE	9.0	11.7	14.4	17.1	19.9	22.6	25.3
	GROSS TREE	28.3	34.3	40.4	46.4	52.4	58.4	64.4
18	LUMBER	18.9	22.2	25.5	28.8	32.1	35.4	38.7
	SAWDUST	3.1	3.7	4.4	5.0	5.6	6.3	6.9
	RESIDUE	10.1	12.7	15.4	18.1	20.8	23.5	26.2
	GROSS TREE	32.0	38.7	45.3	51.9	58.6	65.2	71.8
19	LUMBER	21.4	25.2	29.0	32.9	36.7	40.5	44.4
	SAWDUST	3.5	4.2	4.9	5.6	6.3	7.0	7.7
	RESIDUE	11.2	13.8	16.5	19.1	21.8	24.5	27.1
	GROSS TREE	36.0	43.3	50.5	57.8	65.1	72.4	79.7
20	LUMBER	24.0	28.4	32.8	37.2	41.6	46.0	50.4
	SAWDUST	3.9	4.7	5.4	6.2	7.0	7.8	8.6
	RESIDUE	12.4	15.0	17.6	20.2	22.8	25.5	28.1
	GROSS TREE	40.1	48.1	56.1	64.0	72.0	79.9	87.9
21	LUMBER	26.7	31.7	36.7	41.7	46.7	51.7	56.7
	SAWDUST	4.3	5.2	6.0	6.9	7.8	8.6	9.5
	RESIDUE	13.6	16.2	18.8	21.4	23.9	26.5	29.1
	GROSS TREE	44.5	53.2	61.9	70.5	79.2	87.9	96.6
22	LUMBER	29.6	35.2	40.8	46.5	52.1	57.7	63.3
	SAWDUST	4.8	5.7	6.6	7.6	8.5	9.5	10.4
	RESIDUE	14.9	17.5	20.0	22.6	25.1	27.7	30.2
	GROSS TREE	49.1	58.5	67.9	77.4	86.8	96.2	105.7
23	LUMBER	32.6	38.9	45.2	51.4	57.7	64.0	70.3
	SAWDUST	5.2	6.3	7.3	8.3	9.3	10.4	11.4
	RESIDUE	16.3	18.8	21.3	23.8	26.3	28.8	31.3
	GROSS TREE	53.9	64.1	74.3	84.5	94.7	104.9	115.2
24	LUMBER	35.8	42.7	49.7	56.6	63.6	70.6	77.5
	SAWDUST	5.7	6.8	8.0	9.1	10.2	11.3	12.4
	RESIDUE	17.7	20.2	22.6	25.1	27.6	30.0	32.5
	GROSS TREE	58.9	69.9	81.0	92.0	103.0	114.1	125.1
25	LUMBER	39.0	46.7	54.4	62.1	69.7	77.4	85.1
	SAWDUST	6.2	7.4	8.7	9.9	11.1	12.3	13.5
	RESIDUE	19.2	21.6	24.0	26.5	28.9	31.3	33.8
	GROSS TREE	64.1	76.0	87.9	99.8	111.7	123.6	135.5
26	LUMBER	42.5	50.9	59.3	67.7	76.1	84.5	92.9
	SAWDUST	6.8	8.1	9.4	10.7	12.0	13.3	14.6
	RESIDUE	20.7	23.1	25.5	27.9	30.3	32.6	35.0
	GROSS TREE	69.5	82.3	95.1	107.9	120.7	133.4	146.2
27	LUMBER	46.0	55.2	64.4	73.6	82.7	91.9	101.1
	SAWDUST	7.3	8.7	10.1	11.6	13.0	14.4	15.8
	RESIDUE	22.3	24.7	27.0	29.3	31.7	34.0	36.4
	GROSS TREE	75.2	88.9	102.6	116.3	130.0	143.7	157.4
28	LUMBER	49.7	59.7	69.7	79.6	89.6	99.6	109.6
	SAWDUST	7.9	9.4	10.9	12.4	14.0	15.5	17.0
	RESIDUE	24.0	26.3	28.6	30.9	33.2	35.5	37.8
	GROSS TREE	81.0	95.7	110.4	125.0	139.7	154.4	169.1
29	LUMBER	53.5	64.3	75.1	85.9	96.7	107.5	118.3
	SAWDUST	8.5	10.1	11.7	13.4	15.0	16.6	18.3
	RESIDUE	25.7	27.9	30.2	32.4	34.7	36.9	39.2
	GROSS TREE	87.1	102.8	118.4	134.1	149.8	165.4	181.1
30	LUMBER	57.5	69.1	80.8	92.5	104.1	115.8	127.4
	SAWDUST	9.1	10.8	12.6	14.3	16.1	17.8	19.5
	RESIDUE	27.5	29.7	31.9	34.1	36.3	38.5	40.7
	GROSS TREE	93.4	110.1	126.8	143.5	160.2	176.9	193.6

TABLE 4.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM BLACK OAK BY BAND MILLS (CUBIC FEET)

		MERCHANTABLE HEIGHT (FEET)						
DBH (INCHES)	PRODUCT	24	32	40	48	56	64	72
10	LUMBER	4.0	4.8	5.6	6.4	7.1	7.9	8.7
	SAWDUST	0.7	1.0	1.3	1.5	1.8	2.1	2.4
	RESIDUE	5.5	6.0	6.5	7.0	7.4	7.9	8.4
	GROSS TREE	10.5	12.2	13.8	15.5	17.1	18.8	20.4
11	LUMBER	5.4	6.5	7.6	8.7	9.8	10.9	12.0
	SAWDUST	0.9	1.2	1.6	1.9	2.2	2.5	2.8
	RESIDUE	6.0	6.6	7.1	7.7	8.3	8.9	9.4
	GROSS TREE	12.6	14.7	16.8	18.9	21.0	23.1	25.2
12	LUMBER	6.9	8.4	9.8	11.2	12.7	14.1	15.5
	SAWDUST	1.1	1.5	1.9	2.2	2.6	2.9	3.3
	RESIDUE	6.5	7.2	7.9	8.5	9.2	9.9	10.6
	GROSS TREE	14.8	17.4	20.0	22.6	25.2	27.8	30.4
13	LUMBER	8.6	10.4	12.2	14.0	15.8	17.6	19.4
	SAWDUST	1.4	1.8	2.2	2.6	3.0	3.4	3.8
	RESIDUE	7.1	7.9	8.6	9.4	10.2	11.0	11.8
	GROSS TREE	17.3	20.4	23.5	26.7	29.8	32.9	36.0
14	LUMBER	10.4	12.6	14.8	17.0	19.2	21.4	23.6
	SAWDUST	1.7	2.1	2.6	3.0	3.5	3.9	4.4
	RESIDUE	7.7	8.6	9.5	10.4	11.3	12.2	13.1
	GROSS TREE	19.9	23.6	27.3	31.0	34.7	38.4	42.1
15	LUMBER	12.3	14.9	17.6	20.2	22.8	25.5	28.1
	SAWDUST	1.9	2.4	3.0	3.5	4.0	4.5	5.0
	RESIDUE	8.3	9.4	10.4	11.4	12.5	13.5	14.5
	GROSS TREE	22.8	27.1	31.4	35.7	40.0	44.4	48.7
16	LUMBER	14.4	17.5	20.5	23.6	26.7	29.8	32.9
	SAWDUST	2.2	2.8	3.4	4.0	4.5	5.1	5.7
	RESIDUE	9.0	10.2	11.4	12.5	13.7	14.9	16.1
	GROSS TREE	25.8	30.8	35.8	40.8	45.7	50.7	55.7
17	LUMBER	16.6	20.1	23.7	27.3	30.9	34.4	38.0
	SAWDUST	2.6	3.2	3.8	4.5	5.1	5.7	6.4
	RESIDUE	9.8	11.1	12.4	13.7	15.0	16.4	17.7
	GROSS TREE	29.1	34.8	40.4	46.1	51.8	57.5	63.1
18	LUMBER	18.9	23.0	27.1	31.2	35.3	39.4	43.5
	SAWDUST	2.9	3.6	4.3	5.0	5.7	6.4	7.1
	RESIDUE	10.6	12.0	13.5	15.0	16.5	17.9	19.4
	GROSS TREE	32.5	39.0	45.4	51.8	58.2	64.6	71.1
19	LUMBER	21.3	26.0	30.6	35.3	39.9	44.6	49.2
	SAWDUST	3.2	4.0	4.8	5.6	6.3	7.1	7.9
	RESIDUE	11.4	13.0	14.7	16.3	17.9	19.6	21.2
	GROSS TREE	36.2	43.4	50.6	57.8	65.0	72.2	79.4
20	LUMBER	23.9	29.1	34.4	39.6	44.8	50.0	55.3
	SAWDUST	3.6	4.5	5.3	6.2	7.0	7.9	8.7
	RESIDUE	12.3	14.1	15.9	17.7	19.5	21.3	23.1
	GROSS TREE	40.0	48.0	56.1	64.1	72.2	80.2	88.2
21	LUMBER	26.6	32.5	38.3	44.1	50.0	55.8	61.6
	SAWDUST	4.0	5.0	5.9	6.8	7.7	8.7	9.6
	RESIDUE	13.2	15.2	17.2	19.2	21.2	23.2	25.2
	GROSS TREE	44.0	52.9	61.9	70.8	79.7	88.6	97.5
22	LUMBER	29.5	36.0	42.4	48.9	55.4	61.8	68.3
	SAWDUST	4.4	5.5	6.5	7.5	8.5	9.5	10.5
	RESIDUE	14.2	16.4	18.5	20.7	22.9	25.1	27.3
	GROSS TREE	48.3	58.1	67.9	77.8	87.6	97.4	107.2
23	LUMBER	32.5	39.6	46.7	53.9	61.0	68.1	75.3
	SAWDUST	4.9	6.0	7.1	8.2	9.3	10.4	11.5
	RESIDUE	15.2	17.6	20.0	22.3	24.7	27.1	29.5
	GROSS TREE	52.7	63.5	74.3	85.1	95.8	106.6	117.4
24	LUMBER	35.6	43.4	51.3	59.1	66.9	74.7	82.6
	SAWDUST	5.3	6.5	7.7	8.9	10.1	11.3	12.4
	RESIDUE	16.3	18.9	21.4	24.0	26.6	29.2	31.8
	GROSS TREE	57.3	69.1	80.9	92.7	104.5	116.3	128.0
25	LUMBER	38.8	47.4	56.0	64.5	73.1	81.6	90.2
	SAWDUST	5.8	7.1	8.4	9.6	10.9	12.2	13.5
	RESIDUE	17.4	20.2	23.0	25.8	28.6	31.4	34.2
	GROSS TREE	62.1	75.0	87.8	100.6	113.5	126.3	139.1
26	LUMBER	42.2	51.5	60.8	70.2	79.5	88.8	98.1
	SAWDUST	6.3	7.7	9.1	10.4	11.8	13.2	14.6
	RESIDUE	18.5	21.6	24.6	27.6	30.6	33.7	36.7
	GROSS TREE	67.1	81.1	95.0	108.9	122.8	136.7	150.7
27	LUMBER	45.7	55.8	65.9	76.0	86.1	96.2	106.3
	SAWDUST	6.8	8.3	9.8	11.3	12.7	14.2	15.7
	RESIDUE	19.7	23.0	26.2	29.5	32.8	36.0	39.3
	GROSS TREE	72.4	87.4	102.5	117.5	132.5	147.6	162.6
28	LUMBER	49.4	60.3	71.2	82.1	93.0	103.9	114.8
	SAWDUST	7.3	8.9	10.5	12.1	13.7	15.3	16.9
	RESIDUE	21.0	24.5	28.0	31.5	35.0	38.5	42.0
	GROSS TREE	77.8	94.0	110.2	126.4	142.6	158.9	175.1
29	LUMBER	53.2	64.9	76.7	88.4	100.2	111.9	123.7
	SAWDUST	7.9	9.6	11.3	13.0	14.7	16.4	18.1
	RESIDUE	22.3	26.0	29.8	33.5	37.3	41.0	44.8
	GROSS TREE	83.4	100.8	118.2	135.7	153.1	170.5	188.0
30	LUMBER	57.1	69.7	82.3	95.0	107.6	120.2	132.8
	SAWDUST	8.5	10.3	12.1	13.9	15.7	17.5	19.3
	RESIDUE	23.6	27.6	31.6	35.6	39.7	43.7	47.7
	GROSS TREE	89.2	107.9	126.6	145.2	163.9	182.6	201.3

TABLE 5.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM CHESTNUT OAK BY BAND MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET)						
		24	32	40	48	56	64	72
10	LUMBER	5.3	4.4	3.5	2.6	1.7	0.8	-0.1
	SAWDUST	1.0	1.1	1.1	1.2	1.3	1.3	1.4
	RESIDUE	3.6	5.9	8.2	10.5	12.8	15.1	17.4
	GROSS TREE	9.3	11.0	12.7	14.3	16.0	17.7	19.4
11	LUMBER	6.5	6.0	5.5	5.0	4.5	4.0	3.5
	SAWDUST	1.2	1.3	1.4	1.5	1.6	1.7	1.9
	RESIDUE	4.1	6.5	8.8	11.1	13.4	15.7	18.0
	GROSS TREE	11.3	13.4	15.5	17.6	19.7	21.9	24.0
12	LUMBER	7.7	7.6	7.6	7.5	7.5	7.4	7.4
	SAWDUST	1.4	1.6	1.7	1.9	2.1	2.2	2.4
	RESIDUE	4.8	7.1	9.4	11.7	14.0	16.3	18.6
	GROSS TREE	13.4	16.0	18.6	21.2	23.8	26.4	29.0
13	LUMBER	9.0	9.5	9.9	10.3	10.7	11.2	11.6
	SAWDUST	1.6	1.8	2.1	2.3	2.5	2.8	3.0
	RESIDUE	5.4	7.7	10.1	12.4	14.7	17.0	19.3
	GROSS TREE	15.8	18.9	22.0	25.1	28.3	31.4	34.5
14	LUMBER	10.5	11.4	12.4	13.3	14.3	15.2	16.2
	SAWDUST	1.8	2.1	2.4	2.7	3.0	3.3	3.6
	RESIDUE	6.1	8.5	10.8	13.1	15.5	17.8	20.1
	GROSS TREE	18.3	22.0	25.7	29.4	33.1	36.8	40.5
15	LUMBER	12.0	13.5	15.0	16.5	18.1	19.6	21.1
	SAWDUST	2.1	2.5	2.8	3.2	3.6	4.0	4.3
	RESIDUE	6.9	9.2	11.6	13.9	16.3	18.6	20.9
	GROSS TREE	21.0	25.3	29.6	33.9	38.2	42.5	46.8
16	LUMBER	13.7	15.8	17.9	20.0	22.1	24.2	26.3
	SAWDUST	2.3	2.8	3.2	3.7	4.2	4.6	5.1
	RESIDUE	7.7	10.1	12.4	14.8	17.1	19.5	21.8
	GROSS TREE	23.9	28.9	33.8	38.8	43.7	48.7	53.7
17	LUMBER	15.4	18.2	20.9	23.7	26.4	29.2	31.9
	SAWDUST	2.6	3.1	3.7	4.2	4.8	5.3	5.9
	RESIDUE	8.6	11.0	13.3	15.7	18.0	20.4	22.7
	GROSS TREE	27.0	32.7	38.3	44.0	49.6	55.3	60.9
18	LUMBER	17.3	20.7	24.1	27.6	31.0	34.4	37.9
	SAWDUST	2.9	3.5	4.2	4.8	5.4	6.1	6.7
	RESIDUE	9.6	11.9	14.3	16.6	19.0	21.4	23.7
	GROSS TREE	30.3	36.7	43.1	49.5	55.8	62.2	68.6
19	LUMBER	19.3	23.4	27.6	31.7	35.8	40.0	44.1
	SAWDUST	3.2	3.9	4.7	5.4	6.1	6.9	7.6
	RESIDUE	10.5	12.9	15.3	17.6	20.0	22.4	24.8
	GROSS TREE	33.8	40.9	48.1	55.3	62.4	69.6	76.8
20	LUMBER	21.3	26.2	31.1	36.0	40.9	45.8	50.7
	SAWDUST	3.5	4.3	5.2	6.0	6.8	7.7	8.5
	RESIDUE	11.6	14.0	16.3	18.7	21.1	23.5	25.9
	GROSS TREE	37.4	45.4	53.4	61.4	69.4	77.3	85.3
21	LUMBER	23.5	29.2	34.9	40.6	46.3	52.0	57.7
	SAWDUST	3.9	4.8	5.7	6.7	7.6	8.6	9.5
	RESIDUE	12.7	15.1	17.4	19.8	22.2	24.6	27.0
	GROSS TREE	41.3	50.1	59.0	67.8	76.7	85.5	94.3
22	LUMBER	25.8	32.4	38.9	45.4	51.9	58.4	65.0
	SAWDUST	4.2	5.3	6.3	7.4	8.4	9.5	10.5
	RESIDUE	13.8	16.2	18.6	21.0	23.4	25.8	28.2
	GROSS TREE	45.3	55.1	64.8	74.6	84.3	94.0	103.8
23	LUMBER	28.2	35.6	43.0	50.4	57.8	65.2	72.6
	SAWDUST	4.6	5.7	6.9	8.1	9.3	10.4	11.6
	RESIDUE	15.0	17.4	19.8	22.3	24.7	27.1	29.5
	GROSS TREE	49.5	60.2	70.9	81.6	92.3	103.0	113.7
24	LUMBER	30.7	39.0	47.3	55.6	63.9	72.3	80.6
	SAWDUST	5.0	6.3	7.5	8.8	10.1	11.4	12.7
	RESIDUE	16.3	18.7	21.1	23.5	26.0	28.4	30.8
	GROSS TREE	53.9	65.6	77.3	89.0	100.7	112.3	124.0
25	LUMBER	33.4	42.6	51.9	61.1	70.4	79.6	88.9
	SAWDUST	5.4	6.8	8.2	9.6	11.0	12.5	13.9
	RESIDUE	17.6	20.0	22.4	24.9	27.3	29.8	32.2
	GROSS TREE	58.5	71.2	83.9	96.7	109.4	122.1	134.8
26	LUMBER	36.1	46.3	56.6	66.8	77.0	87.3	97.5
	SAWDUST	5.8	7.3	8.9	10.4	12.0	13.6	15.1
	RESIDUE	18.9	21.4	23.8	26.3	28.7	31.2	33.6
	GROSS TREE	63.3	77.1	90.9	104.7	118.4	132.2	146.0
27	LUMBER	38.9	50.2	61.4	72.7	84.0	95.2	106.5
	SAWDUST	6.2	7.9	9.6	11.3	13.0	14.7	16.4
	RESIDUE	20.3	22.8	25.3	27.7	30.2	32.7	35.1
	GROSS TREE	68.3	83.2	98.1	113.0	127.9	142.8	157.7
28	LUMBER	41.8	54.2	66.5	78.8	91.1	103.5	115.8
	SAWDUST	6.7	8.5	10.3	12.2	14.0	15.8	17.7
	RESIDUE	21.8	24.3	26.8	29.2	31.7	34.2	36.7
	GROSS TREE	73.4	89.5	105.5	121.6	137.7	153.7	169.8
29	LUMBER	44.9	58.3	71.7	85.2	98.6	112.0	125.5
	SAWDUST	7.1	9.1	11.1	13.1	15.1	17.1	19.0
	RESIDUE	23.3	25.8	28.3	30.8	33.3	35.8	38.3
	GROSS TREE	78.8	96.0	113.3	130.5	147.8	165.0	182.3
30	LUMBER	48.0	62.6	77.2	91.7	106.3	120.9	135.4
	SAWDUST	7.6	9.8	11.9	14.0	16.2	18.3	20.5
	RESIDUE	24.9	27.4	29.9	32.4	34.9	37.5	40.0
	GROSS TREE	84.3	102.8	121.3	139.8	158.3	176.8	195.3

TABLE 6.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM RED MAPLE BY BAND MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET)						
		24	32	40	48	56	64	72
10	LUMBER	5.0	6.5	8.0	9.6	11.1	12.6	14.1
	SAWDUST	1.0	1.4	1.8	2.2	2.6	2.9	3.3
	RESIDUE	3.3	5.2	7.0	8.8	10.7	12.5	14.3
	GROSS TREE	9.3	12.9	16.5	20.1	23.7	27.3	30.9
11	LUMBER	6.5	8.2	9.9	11.6	13.3	15.0	16.8
	SAWDUST	1.3	1.7	2.1	2.5	2.9	3.3	3.7
	RESIDUE	4.1	5.9	7.7	9.4	11.2	13.0	14.8
	GROSS TREE	11.5	15.3	19.2	23.1	26.9	30.8	34.7
12	LUMBER	8.0	10.0	11.9	13.9	15.8	17.7	19.7
	SAWDUST	1.5	1.9	2.3	2.8	3.2	3.6	4.0
	RESIDUE	4.9	6.7	8.4	10.1	11.9	13.6	15.3
	GROSS TREE	13.9	18.0	22.2	26.4	30.5	34.7	38.8
13	LUMBER	9.7	11.9	14.1	16.3	18.5	20.7	22.9
	SAWDUST	1.7	2.2	2.6	3.1	3.5	4.0	4.4
	RESIDUE	5.8	7.5	9.2	10.9	12.5	14.2	15.9
	GROSS TREE	16.5	21.0	25.5	29.9	34.4	38.9	43.4
14	LUMBER	11.6	14.0	16.5	18.9	21.4	23.9	26.3
	SAWDUST	2.0	2.5	3.0	3.4	3.9	4.4	4.9
	RESIDUE	6.8	8.4	10.0	11.6	13.3	14.9	16.5
	GROSS TREE	19.4	24.2	29.0	33.8	38.6	43.4	48.3
15	LUMBER	13.5	16.3	19.0	21.8	24.5	27.3	30.0
	SAWDUST	2.3	2.8	3.3	3.8	4.3	4.8	5.3
	RESIDUE	7.9	9.4	11.0	12.5	14.0	15.6	17.1
	GROSS TREE	22.4	27.6	32.8	38.0	43.1	48.3	53.5
16	LUMBER	15.6	18.7	21.8	24.8	27.9	30.9	34.0
	SAWDUST	2.6	3.2	3.7	4.2	4.8	5.3	5.8
	RESIDUE	9.0	10.5	11.9	13.4	14.9	16.4	17.8
	GROSS TREE	25.7	31.2	36.8	42.4	48.0	53.5	59.1
17	LUMBER	17.9	21.3	24.7	28.0	31.4	34.8	38.2
	SAWDUST	3.0	3.5	4.1	4.7	5.2	5.8	6.3
	RESIDUE	10.2	11.6	13.0	14.4	15.8	17.2	18.6
	GROSS TREE	29.1	35.1	41.1	47.1	53.1	59.1	65.1
18	LUMBER	20.3	24.0	27.7	31.5	35.2	38.9	42.6
	SAWDUST	3.3	3.9	4.5	5.1	5.7	6.3	6.9
	RESIDUE	11.5	12.8	14.1	15.4	16.7	18.0	19.3
	GROSS TREE	32.8	39.3	45.7	52.1	58.6	65.0	71.4
19	LUMBER	22.8	26.9	31.0	35.1	39.2	43.3	47.4
	SAWDUST	3.7	4.4	5.0	5.6	6.2	6.9	7.5
	RESIDUE	12.8	14.0	15.3	16.5	17.7	18.9	20.2
	GROSS TREE	36.7	43.6	50.5	57.4	64.3	71.2	78.1
20	LUMBER	25.4	29.9	34.4	38.9	43.4	47.8	52.3
	SAWDUST	4.1	4.8	5.5	6.1	6.8	7.4	8.1
	RESIDUE	14.2	15.4	16.5	17.6	18.8	19.9	21.0
	GROSS TREE	40.8	48.2	55.6	63.0	70.4	77.8	85.2
21	LUMBER	28.2	33.1	38.0	42.9	47.8	52.7	57.6
	SAWDUST	4.6	5.3	6.0	6.7	7.4	8.1	8.8
	RESIDUE	15.7	16.8	17.8	18.8	19.9	20.9	22.0
	GROSS TREE	45.1	53.1	61.0	68.9	76.8	84.7	92.6
22	LUMBER	31.2	36.5	41.8	47.1	52.4	57.7	63.0
	SAWDUST	5.0	5.7	6.5	7.2	8.0	8.7	9.4
	RESIDUE	17.3	18.2	19.2	20.1	21.0	22.0	22.9
	GROSS TREE	49.7	58.1	66.6	75.0	83.5	92.0	100.4
23	LUMBER	34.2	40.0	45.7	51.5	57.3	63.0	68.8
	SAWDUST	5.5	6.2	7.0	7.8	8.6	9.4	10.2
	RESIDUE	18.9	19.8	20.6	21.4	22.3	23.1	23.9
	GROSS TREE	54.4	63.4	72.5	81.5	90.5	99.5	108.6
24	LUMBER	37.4	43.6	49.9	56.1	62.3	68.5	74.8
	SAWDUST	5.9	6.8	7.6	8.4	9.2	10.1	10.9
	RESIDUE	20.6	21.4	22.1	22.8	23.5	24.3	25.0
	GROSS TREE	59.3	69.0	78.6	88.2	97.8	107.5	117.1
25	LUMBER	40.8	47.5	54.2	60.9	67.6	74.3	81.0
	SAWDUST	6.5	7.3	8.2	9.1	9.9	10.8	11.7
	RESIDUE	22.4	23.0	23.6	24.3	24.9	25.5	26.1
	GROSS TREE	64.5	74.7	85.0	95.2	105.5	115.7	126.0
26	LUMBER	44.2	51.4	58.7	65.9	73.1	80.3	87.5
	SAWDUST	7.0	7.9	8.8	9.7	10.7	11.6	12.5
	RESIDUE	24.3	24.8	25.3	25.7	26.2	26.7	27.2
	GROSS TREE	69.9	80.8	91.6	102.5	113.4	124.3	135.2
27	LUMBER	47.8	55.6	63.3	71.1	78.8	86.5	94.3
	SAWDUST	7.5	8.5	9.5	10.4	11.4	12.4	13.3
	RESIDUE	26.2	26.6	26.9	27.3	27.7	28.0	28.4
	GROSS TREE	75.4	87.0	98.6	110.1	121.7	133.3	144.8
28	LUMBER	51.6	59.9	68.2	76.4	84.7	93.0	101.3
	SAWDUST	8.1	9.1	10.1	11.1	12.2	13.2	14.2
	RESIDUE	28.2	28.5	28.7	28.9	29.2	29.4	29.6
	GROSS TREE	81.2	93.5	105.7	118.0	130.3	142.5	154.8
29	LUMBER	55.5	64.3	73.2	82.0	90.9	99.7	108.6
	SAWDUST	8.7	9.8	10.8	11.9	13.0	14.0	15.1
	RESIDUE	30.3	30.4	30.5	30.6	30.7	30.8	30.9
	GROSS TREE	87.2	100.2	113.2	126.2	139.1	152.1	165.1
30	LUMBER	59.5	68.9	78.3	87.8	97.2	106.7	116.1
	SAWDUST	9.3	10.4	11.5	12.7	13.8	14.9	16.0
	RESIDUE	32.4	32.4	32.4	32.3	32.3	32.3	32.2
	GROSS TREE	93.4	107.2	120.9	134.6	148.3	162.1	175.8

TABLE 7.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM RED MAPLE BY CIRCULAR MILLS (CUBIC FEET)

		MERCHANTABLE HEIGHT (FEET)						
DBH (INCHES)	PRODUCT	24	32	40	48	56	64	72
10	LUMBER	2.1	3.9	5.6	7.4	9.2	11.0	12.8
	SAWDUST	0.9	1.4	1.9	2.5	3.0	3.5	4.1
	RESIDUE	3.3	5.2	7.0	8.8	10.7	12.5	14.3
	GROSS TREE	9.3	12.9	16.5	20.1	23.7	27.3	30.9
11	LUMBER	3.4	5.4	7.4	9.3	11.3	13.3	15.3
	SAWDUST	1.2	1.8	2.4	3.0	3.6	4.2	4.8
	RESIDUE	4.1	5.9	7.7	9.4	11.2	13.0	14.8
	GROSS TREE	11.5	15.3	19.2	23.1	26.9	30.8	34.7
12	LUMBER	4.8	7.0	9.2	11.4	13.6	15.9	18.1
	SAWDUST	1.6	2.3	2.9	3.6	4.2	4.9	5.5
	RESIDUE	4.9	6.7	8.4	10.1	11.9	13.6	15.3
	GROSS TREE	13.9	18.0	22.2	26.4	30.5	34.7	38.8
13	LUMBER	6.4	8.8	11.3	13.7	16.2	18.6	21.1
	SAWDUST	2.0	2.8	3.5	4.2	4.9	5.7	6.4
	RESIDUE	5.8	7.5	9.2	10.9	12.5	14.2	15.9
	GROSS TREE	16.5	21.0	25.5	29.9	34.4	38.9	43.4
14	LUMBER	8.1	10.8	13.5	16.2	18.9	21.6	24.3
	SAWDUST	2.5	3.3	4.1	4.9	5.7	6.5	7.3
	RESIDUE	6.8	8.4	10.0	11.6	13.3	14.9	16.5
	GROSS TREE	19.4	24.2	29.0	33.8	38.6	43.4	48.3
15	LUMBER	9.9	12.9	15.8	18.8	21.8	24.8	27.8
	SAWDUST	3.0	3.9	4.7	5.6	6.5	7.4	8.2
	RESIDUE	7.9	9.4	11.0	12.5	14.0	15.6	17.1
	GROSS TREE	22.4	27.6	32.8	38.0	43.1	48.3	53.5
16	LUMBER	11.8	15.1	18.4	21.6	24.9	28.2	31.5
	SAWDUST	3.5	4.5	5.4	6.4	7.4	8.3	9.3
	RESIDUE	9.0	10.5	11.9	13.4	14.9	16.4	17.8
	GROSS TREE	25.7	31.2	36.8	42.4	48.0	53.5	59.1
17	LUMBER	13.9	17.5	21.1	24.7	28.3	31.9	35.5
	SAWDUST	4.1	5.1	6.2	7.2	8.3	9.3	10.4
	RESIDUE	10.2	11.6	13.0	14.4	15.8	17.2	18.6
	GROSS TREE	29.1	35.1	41.1	47.1	53.1	59.1	65.1
18	LUMBER	16.0	20.0	23.9	27.8	31.8	35.7	39.7
	SAWDUST	4.6	5.8	6.9	8.1	9.2	10.4	11.5
	RESIDUE	11.5	12.8	14.1	15.4	16.7	18.0	19.3
	GROSS TREE	32.8	39.3	45.7	52.1	58.6	65.0	71.4
19	LUMBER	18.4	22.6	26.9	31.2	35.5	39.8	44.1
	SAWDUST	5.3	6.5	7.8	9.0	10.3	11.5	12.8
	RESIDUE	12.8	14.0	15.3	16.5	17.7	18.9	20.2
	GROSS TREE	36.7	43.6	50.5	57.4	64.3	71.2	78.1
20	LUMBER	20.8	25.5	30.1	34.8	39.4	44.1	48.8
	SAWDUST	5.9	7.3	8.6	10.0	11.4	12.7	14.1
	RESIDUE	14.2	15.4	16.5	17.6	18.8	19.9	21.0
	GROSS TREE	40.8	48.2	55.6	63.0	70.4	77.8	85.2
21	LUMBER	23.3	28.4	33.5	38.5	43.6	48.6	53.7
	SAWDUST	6.6	8.1	9.6	11.0	12.5	14.0	15.5
	RESIDUE	15.7	16.8	17.8	18.8	19.9	20.9	22.0
	GROSS TREE	45.1	53.1	61.0	68.9	76.8	84.7	92.6
22	LUMBER	26.0	31.5	37.0	42.4	47.9	53.4	58.8
	SAWDUST	7.3	8.9	10.5	12.1	13.7	15.3	16.9
	RESIDUE	17.3	18.2	19.2	20.1	21.0	22.0	22.9
	GROSS TREE	49.7	58.1	66.6	75.0	83.5	92.0	100.4
23	LUMBER	28.8	34.7	40.6	46.5	52.4	58.3	64.2
	SAWDUST	8.1	9.8	11.5	13.2	15.0	16.7	18.4
	RESIDUE	18.9	19.8	20.6	21.4	22.3	23.1	23.9
	GROSS TREE	54.4	63.4	72.5	81.5	90.5	99.5	108.6
24	LUMBER	31.8	38.1	44.5	50.8	57.2	63.5	69.9
	SAWDUST	8.9	10.7	12.6	14.4	16.3	18.1	20.0
	RESIDUE	20.6	21.4	22.1	22.8	23.5	24.3	25.0
	GROSS TREE	59.3	69.0	78.6	88.2	97.8	107.5	117.1
25	LUMBER	34.8	41.7	48.5	55.3	62.1	68.9	75.8
	SAWDUST	9.7	11.7	13.7	15.7	17.6	19.6	21.6
	RESIDUE	22.4	23.0	23.6	24.3	24.9	25.5	26.1
	GROSS TREE	64.5	74.7	85.0	95.2	105.5	115.7	126.0
26	LUMBER	38.0	45.3	52.6	59.9	67.3	74.6	81.9
	SAWDUST	10.6	12.7	14.8	16.9	19.0	21.2	23.3
	RESIDUE	24.3	24.8	25.3	25.7	26.2	26.7	27.2
	GROSS TREE	69.9	80.8	91.6	102.5	113.4	124.3	135.2
27	LUMBER	41.3	49.1	57.0	64.8	72.6	80.4	88.2
	SAWDUST	11.5	13.7	16.0	18.3	20.5	22.8	25.1
	RESIDUE	26.2	26.6	26.9	27.3	27.7	28.0	28.4
	GROSS TREE	75.4	87.0	98.6	110.1	121.7	133.3	144.8
28	LUMBER	44.8	53.1	61.4	69.8	78.1	86.5	94.8
	SAWDUST	12.4	14.8	17.2	19.6	22.1	24.5	26.9
	RESIDUE	28.2	28.5	28.7	28.9	29.2	29.4	29.6
	GROSS TREE	81.2	93.5	105.7	118.0	130.3	142.5	154.8
29	LUMBER	48.3	57.2	66.1	75.0	83.9	92.8	101.7
	SAWDUST	13.4	15.9	18.5	21.1	23.6	26.2	28.8
	RESIDUE	30.3	30.4	30.5	30.6	30.7	30.8	30.9
	GROSS TREE	87.2	100.2	113.2	126.2	139.1	152.1	165.1
30	LUMBER	52.0	61.5	70.9	80.4	89.8	99.3	108.7
	SAWDUST	14.3	17.1	19.8	22.6	25.3	28.0	30.8
	RESIDUE	32.4	32.4	32.4	32.3	32.3	32.3	32.2
	GROSS TREE	93.4	107.2	120.9	134.6	148.3	162.1	175.8

TABLE 8.—PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM SUGAR MAPLE BY BAND MILLS (CUBIC FEET)

		MERCHANTABLE HEIGHT (FEET)						
DBH (INCHES)	PRODUCT	24	32	40	48	56	64	72
10	LUMBER	5.9	7.4	9.0	10.5	12.0	13.6	15.1
	SAWDUST	1.2	1.5	1.7	2.0	2.3	2.5	2.8
	RESIDUE	2.7	3.7	4.6	5.6	6.5	7.5	8.4
	GROSS TREE	10.0	12.8	15.6	18.4	21.2	24.0	26.8
11	LUMBER	7.0	8.7	10.5	12.2	13.9	15.7	17.4
	SAWDUST	1.3	1.6	1.9	2.2	2.5	2.8	3.1
	RESIDUE	3.5	4.5	5.5	6.5	7.5	8.5	9.5
	GROSS TREE	12.0	15.1	18.3	21.4	24.5	27.7	30.8
12	LUMBER	8.2	10.1	12.1	14.1	16.0	18.0	20.0
	SAWDUST	1.5	1.8	2.2	2.5	2.8	3.2	3.5
	RESIDUE	4.3	5.4	6.4	7.5	8.6	9.7	10.7
	GROSS TREE	14.2	17.7	21.2	24.7	28.2	31.6	35.1
13	LUMBER	9.5	11.7	13.9	16.1	18.3	20.5	22.7
	SAWDUST	1.7	2.1	2.4	2.8	3.1	3.5	3.9
	RESIDUE	5.2	6.3	7.5	8.6	9.7	10.9	12.0
	GROSS TREE	16.6	20.5	24.3	28.2	32.1	36.0	39.9
14	LUMBER	10.9	13.3	15.8	18.3	20.7	23.2	25.7
	SAWDUST	1.9	2.3	2.7	3.1	3.5	3.9	4.3
	RESIDUE	6.1	7.3	8.6	9.8	11.0	12.2	13.4
	GROSS TREE	19.1	23.4	27.7	32.1	36.4	40.7	45.0
15	LUMBER	12.4	15.1	17.9	20.6	23.4	26.1	28.8
	SAWDUST	2.1	2.5	3.0	3.4	3.9	4.3	4.7
	RESIDUE	7.2	8.5	9.7	11.0	12.3	13.6	14.9
	GROSS TREE	21.9	26.6	31.4	36.2	40.9	45.7	50.5
16	LUMBER	14.0	17.0	20.1	23.1	26.2	29.2	32.3
	SAWDUST	2.3	2.8	3.3	3.8	4.2	4.7	5.2
	RESIDUE	8.3	9.6	11.0	12.4	13.8	15.2	16.5
	GROSS TREE	24.8	30.1	35.3	40.6	45.8	51.1	56.3
17	LUMBER	15.7	19.1	22.4	25.8	29.1	32.5	35.9
	SAWDUST	2.5	3.1	3.6	4.1	4.7	5.2	5.7
	RESIDUE	9.4	10.9	12.4	13.8	15.3	16.8	18.3
	GROSS TREE	27.9	33.7	39.5	45.3	51.0	56.8	62.6
18	LUMBER	17.5	21.2	24.9	28.6	32.3	36.0	39.7
	SAWDUST	2.8	3.4	3.9	4.5	5.1	5.7	6.3
	RESIDUE	10.7	12.2	13.8	15.4	16.9	18.5	20.1
	GROSS TREE	31.3	37.6	43.9	50.2	56.6	62.9	69.2
19	LUMBER	19.4	23.5	27.5	31.6	35.7	39.7	43.8
	SAWDUST	3.1	3.7	4.3	4.9	5.6	6.2	6.8
	RESIDUE	12.0	13.6	15.3	17.0	18.7	20.3	22.0
	GROSS TREE	34.8	41.7	48.6	55.5	62.4	69.3	76.2
20	LUMBER	21.4	25.9	30.3	34.8	39.2	43.6	48.1
	SAWDUST	3.3	4.0	4.7	5.4	6.1	6.8	7.4
	RESIDUE	13.4	15.1	16.9	18.7	20.5	22.2	24.0
	GROSS TREE	38.5	46.0	53.5	61.0	68.6	76.1	83.6
21	LUMBER	23.6	28.4	33.2	38.1	42.9	47.7	52.6
	SAWDUST	3.6	4.4	5.1	5.8	6.6	7.3	8.1
	RESIDUE	14.8	16.7	18.6	20.5	22.4	24.3	26.1
	GROSS TREE	42.3	50.5	58.7	66.9	75.0	83.2	91.4
22	LUMBER	25.8	31.0	36.3	41.5	46.8	52.0	57.3
	SAWDUST	3.9	4.7	5.5	6.3	7.1	7.9	8.7
	RESIDUE	16.3	18.3	20.4	22.4	24.4	26.4	28.4
	GROSS TREE	46.4	55.3	64.1	73.0	81.8	90.7	99.5
23	LUMBER	28.1	33.8	39.5	45.2	50.9	56.6	62.2
	SAWDUST	4.2	5.1	6.0	6.8	7.7	8.6	9.4
	RESIDUE	17.9	20.1	22.2	24.3	26.5	28.6	30.7
	GROSS TREE	50.7	60.2	69.8	79.4	88.9	98.5	108.1
24	LUMBER	30.6	36.7	42.8	49.0	55.1	61.3	67.4
	SAWDUST	4.6	5.5	6.4	7.4	8.3	9.2	10.2
	RESIDUE	19.6	21.9	24.1	26.4	28.6	30.9	33.2
	GROSS TREE	55.1	65.4	75.7	86.0	96.3	106.6	117.0
25	LUMBER	33.1	39.7	46.3	52.9	59.6	66.2	72.8
	SAWDUST	4.9	5.9	6.9	7.9	8.9	9.9	10.9
	RESIDUE	21.3	23.7	26.1	28.5	30.9	33.3	35.7
	GROSS TREE	59.8	70.8	81.9	93.0	104.1	115.2	126.2
26	LUMBER	35.7	42.8	50.0	57.1	64.2	71.3	78.4
	SAWDUST	5.3	6.4	7.4	8.5	9.6	10.6	11.7
	RESIDUE	23.1	25.7	28.2	30.7	33.3	35.8	38.3
	GROSS TREE	64.6	76.5	88.4	100.2	112.1	124.0	135.9
27	LUMBER	38.5	46.1	53.7	61.3	69.0	76.6	84.2
	SAWDUST	5.7	6.8	8.0	9.1	10.2	11.4	12.5
	RESIDUE	25.0	27.7	30.4	33.1	35.7	38.4	41.1
	GROSS TREE	69.6	82.3	95.1	107.8	120.5	133.2	145.9
28	LUMBER	41.3	49.5	57.6	65.8	73.9	82.1	90.3
	SAWDUST	6.1	7.3	8.5	9.7	10.9	12.1	13.4
	RESIDUE	27.0	29.8	32.6	35.5	38.3	41.1	44.0
	GROSS TREE	74.8	88.4	102.0	115.6	129.2	142.8	156.3
29	LUMBER	44.3	53.0	61.7	70.4	79.1	87.8	96.5
	SAWDUST	6.5	7.8	9.1	10.4	11.7	12.9	14.2
	RESIDUE	29.0	32.0	35.0	38.0	40.9	43.9	46.9
	GROSS TREE	80.2	94.7	109.2	123.7	138.2	152.7	167.1
30	LUMBER	47.3	56.6	65.9	75.2	84.4	93.7	103.0
	SAWDUST	6.9	8.3	9.6	11.0	12.4	13.8	15.2
	RESIDUE	31.1	34.2	37.4	40.5	43.7	46.8	50.0
	GROSS TREE	85.8	101.2	116.7	132.1	147.5	162.9	178.3

TABLE 9.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM YELLOW-POPLAR BY BAND MILLS (CUBIC FEET)

		MERCHANTABLE HEIGHT (FEET)						
DBH (INCHES)	PRODUCT	24	32	40	48	56	64	72
10	LUMBER	3.8	3.9	3.9	4.0	4.0	4.1	4.2
	SAWDUST	0.8	0.9	1.0	1.1	1.2	1.3	1.4
	RESIDUE	5.0	6.1	7.1	8.2	9.3	10.3	11.4
	GROSS TREE	10.3	11.7	13.0	14.3	15.7	17.0	18.4
11	LUMBER	5.5	5.9	6.2	6.6	6.9	7.3	7.6
	SAWDUST	1.1	1.2	1.4	1.5	1.7	1.8	2.0
	RESIDUE	5.3	6.4	7.5	8.6	9.8	10.9	12.0
	GROSS TREE	12.4	14.2	16.0	17.8	19.6	21.3	23.1
12	LUMBER	7.3	8.0	8.7	9.4	10.1	10.7	11.4
	SAWDUST	1.3	1.5	1.8	2.0	2.2	2.4	2.6
	RESIDUE	5.6	6.8	8.0	9.2	10.3	11.5	12.7
	GROSS TREE	14.8	17.0	19.3	21.5	23.8	26.0	28.3
13	LUMBER	9.3	10.3	11.4	12.4	13.5	14.5	15.5
	SAWDUST	1.6	1.9	2.2	2.4	2.7	3.0	3.2
	RESIDUE	6.0	7.2	8.5	9.7	10.9	12.2	13.4
	GROSS TREE	17.3	20.1	22.9	25.6	28.4	31.1	33.9
14	LUMBER	11.4	12.9	14.3	15.7	17.2	18.6	20.0
	SAWDUST	1.9	2.3	2.6	2.9	3.3	3.6	4.0
	RESIDUE	6.4	7.7	9.0	10.3	11.6	12.9	14.2
	GROSS TREE	20.1	23.4	26.7	30.0	33.3	36.6	39.9
15	LUMBER	13.7	15.6	17.4	19.3	21.1	23.0	24.8
	SAWDUST	2.3	2.7	3.1	3.5	3.9	4.3	4.7
	RESIDUE	6.8	8.2	9.5	10.9	12.3	13.7	15.1
	GROSS TREE	23.1	27.0	30.9	34.7	38.6	42.5	46.4
16	LUMBER	16.2	18.5	20.8	23.1	25.3	27.6	29.9
	SAWDUST	2.6	3.1	3.6	4.1	4.6	5.0	5.5
	RESIDUE	7.2	8.7	10.1	11.6	13.1	14.5	16.0
	GROSS TREE	26.2	30.8	35.3	39.8	44.3	48.8	53.4
17	LUMBER	18.8	21.6	24.3	27.1	29.8	32.6	35.4
	SAWDUST	3.0	3.6	4.1	4.7	5.3	5.8	6.4
	RESIDUE	7.7	9.2	10.8	12.3	13.9	15.4	17.0
	GROSS TREE	29.6	34.8	40.0	45.2	50.4	55.6	60.7
18	LUMBER	21.6	24.8	28.1	31.4	34.6	37.9	41.1
	SAWDUST	3.4	4.1	4.7	5.4	6.0	6.7	7.3
	RESIDUE	8.2	9.8	11.5	13.1	14.7	16.4	18.0
	GROSS TREE	33.2	39.1	45.0	50.9	56.8	62.7	68.6
19	LUMBER	24.5	28.3	32.1	35.9	39.7	43.5	47.3
	SAWDUST	3.9	4.6	5.3	6.1	6.8	7.5	8.3
	RESIDUE	8.7	10.4	12.2	13.9	15.6	17.4	19.1
	GROSS TREE	37.0	43.6	50.3	56.9	63.6	70.2	76.9
20	LUMBER	27.6	32.0	36.3	40.7	45.0	49.3	53.7
	SAWDUST	4.3	5.1	6.0	6.8	7.6	8.5	9.3
	RESIDUE	9.3	11.1	12.9	14.8	16.6	18.4	20.3
	GROSS TREE	40.9	48.4	55.8	63.3	70.7	78.2	85.6
21	LUMBER	30.9	35.8	40.7	45.7	50.6	55.5	60.5
	SAWDUST	4.8	5.7	6.6	7.6	8.5	9.4	10.4
	RESIDUE	9.9	11.8	13.7	15.7	17.6	19.5	21.5
	GROSS TREE	45.1	53.4	61.7	70.0	78.3	86.5	94.8
22	LUMBER	34.3	39.8	45.4	50.9	56.5	62.0	67.6
	SAWDUST	5.3	6.3	7.3	8.4	9.4	10.4	11.5
	RESIDUE	10.5	12.5	14.6	16.6	18.6	20.7	22.7
	GROSS TREE	49.5	58.7	67.8	77.0	86.1	95.3	104.4
23	LUMBER	37.8	44.0	50.2	56.4	62.6	68.8	75.0
	SAWDUST	5.8	6.9	8.1	9.2	10.4	11.5	12.7
	RESIDUE	11.1	13.3	15.4	17.6	19.7	21.9	24.1
	GROSS TREE	54.1	64.2	74.3	84.3	94.4	104.5	114.5
24	LUMBER	41.6	48.4	55.3	62.2	69.0	75.9	82.8
	SAWDUST	6.3	7.6	8.9	10.1	11.4	12.6	13.9
	RESIDUE	11.8	14.1	16.3	18.6	20.9	23.2	25.5
	GROSS TREE	58.9	70.0	81.0	92.0	103.0	114.0	125.1
25	LUMBER	45.4	53.0	60.6	68.1	75.7	83.3	90.8
	SAWDUST	6.9	8.3	9.7	11.0	12.4	13.8	15.2
	RESIDUE	12.5	14.9	17.3	19.7	22.1	24.5	26.9
	GROSS TREE	63.9	76.0	88.0	100.0	112.0	124.0	136.0
26	LUMBER	49.5	57.8	66.1	74.4	82.7	91.0	99.3
	SAWDUST	7.5	9.0	10.5	12.0	13.5	15.0	16.5
	RESIDUE	13.2	15.8	18.3	20.8	23.3	25.9	28.4
	GROSS TREE	69.1	82.2	95.3	108.3	121.4	134.4	147.5
27	LUMBER	53.7	62.7	71.8	80.9	89.9	99.0	108.0
	SAWDUST	8.1	9.8	11.4	13.0	14.6	16.3	17.9
	RESIDUE	14.0	16.6	19.3	22.0	24.6	27.3	30.0
	GROSS TREE	74.6	88.7	102.8	117.0	131.1	145.2	159.3
28	LUMBER	58.0	67.9	77.7	87.6	97.4	107.3	117.1
	SAWDUST	8.8	10.5	12.3	14.0	15.8	17.6	19.3
	RESIDUE	14.8	17.6	20.4	23.2	26.0	28.8	31.6
	GROSS TREE	80.2	95.4	110.7	125.9	141.2	156.4	171.7
29	LUMBER	62.6	73.2	83.9	94.5	105.2	115.9	126.5
	SAWDUST	9.4	11.3	13.2	15.1	17.0	18.9	20.8
	RESIDUE	15.6	18.5	21.5	24.4	27.4	30.3	33.3
	GROSS TREE	86.0	102.4	118.8	135.2	151.6	168.0	184.4
30	LUMBER	67.2	78.7	90.2	101.7	113.3	124.8	136.3
	SAWDUST	10.1	12.1	14.2	16.2	18.3	20.3	22.4
	RESIDUE	16.4	19.5	22.6	25.7	28.8	31.9	35.0
	GROSS TREE	92.0	109.6	127.2	144.8	162.5	180.1	197.7

TABLE 10.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM YELLOW-POPLAR BY CIRCULAR MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET) 24	32	40	48	56	64	72
10	LUMBER	4.0	4.6	5.2	5.8	6.4	7.0	7.6
	SAWDUST	1.4	1.8	2.1	2.4	2.7	3.1	3.4
	RESIDUE	5.0	6.1	7.1	8.2	9.3	10.3	11.4
	GROSS TREE	10.3	11.7	13.0	14.3	15.7	17.0	18.4
11	LUMBER	5.4	6.3	7.2	8.1	8.9	9.8	10.7
	SAWDUST	1.8	2.2	2.6	3.0	3.4	3.8	4.2
	RESIDUE	5.3	6.4	7.5	8.6	9.8	10.9	12.0
	GROSS TREE	12.4	14.2	16.0	17.8	19.6	21.3	23.1
12	LUMBER	6.9	8.1	9.3	10.5	11.7	12.9	14.1
	SAWDUST	2.2	2.7	3.2	3.7	4.2	4.7	5.2
	RESIDUE	5.6	6.8	8.0	9.2	10.3	11.5	12.7
	GROSS TREE	14.8	17.0	19.3	21.5	23.8	26.0	28.3
13	LUMBER	8.6	10.1	11.6	13.1	14.7	16.2	17.7
	SAWDUST	2.6	3.2	3.8	4.4	5.0	5.6	6.2
	RESIDUE	6.0	7.2	8.5	9.7	10.9	12.2	13.4
	GROSS TREE	17.3	20.1	22.9	25.6	28.4	31.1	33.9
14	LUMBER	10.4	12.3	14.1	16.0	17.9	19.8	21.6
	SAWDUST	3.1	3.8	4.5	5.2	5.9	6.6	7.3
	RESIDUE	6.4	7.7	9.0	10.3	11.6	12.9	14.2
	GROSS TREE	20.1	23.4	26.7	30.0	33.3	36.6	39.9
15	LUMBER	12.3	14.6	16.8	19.1	21.3	23.6	25.9
	SAWDUST	3.6	4.4	5.2	6.0	6.8	7.6	8.4
	RESIDUE	6.8	8.2	9.5	10.9	12.3	13.7	15.1
	GROSS TREE	23.1	27.0	30.9	34.7	38.6	42.5	46.4
16	LUMBER	14.3	17.0	19.7	22.4	25.0	27.7	30.4
	SAWDUST	4.1	5.0	6.0	6.9	7.8	8.8	9.7
	RESIDUE	7.2	8.7	10.1	11.6	13.1	14.5	16.0
	GROSS TREE	26.2	30.8	35.3	39.8	44.3	48.8	53.4
17	LUMBER	16.5	19.6	22.7	25.9	29.0	32.1	35.2
	SAWDUST	4.7	5.7	6.8	7.9	8.9	10.0	11.0
	RESIDUE	7.7	9.2	10.8	12.3	13.9	15.4	17.0
	GROSS TREE	29.6	34.8	40.0	45.2	50.4	55.6	60.7
18	LUMBER	18.8	22.4	26.0	29.6	33.1	36.7	40.3
	SAWDUST	5.3	6.5	7.7	8.9	10.1	11.2	12.4
	RESIDUE	8.2	9.8	11.5	13.1	14.7	16.4	18.0
	GROSS TREE	33.2	39.1	45.0	50.9	56.8	62.7	68.6
19	LUMBER	21.3	25.4	29.4	33.5	37.6	41.6	45.7
	SAWDUST	5.9	7.3	8.6	9.9	11.3	12.6	13.9
	RESIDUE	8.7	10.4	12.2	13.9	15.6	17.4	19.1
	GROSS TREE	37.0	43.6	50.3	56.9	63.6	70.2	76.9
20	LUMBER	23.9	28.4	33.0	37.6	42.2	46.8	51.4
	SAWDUST	6.6	8.1	9.6	11.0	12.5	14.0	15.5
	RESIDUE	9.3	11.1	12.9	14.8	16.6	18.4	20.3
	GROSS TREE	40.9	48.4	55.8	63.3	70.7	78.2	85.6
21	LUMBER	26.6	31.7	36.8	42.0	47.1	52.2	57.3
	SAWDUST	7.3	8.9	10.6	12.2	13.9	15.5	17.2
	RESIDUE	9.9	11.8	13.7	15.7	17.6	19.5	21.5
	GROSS TREE	45.1	53.4	61.7	70.0	78.3	86.5	94.8
22	LUMBER	29.4	35.1	40.8	46.5	52.2	57.9	63.6
	SAWDUST	8.0	9.8	11.7	13.5	15.3	17.1	18.9
	RESIDUE	10.5	12.5	14.6	16.6	18.6	20.7	22.7
	GROSS TREE	49.5	58.7	67.8	77.0	86.1	95.3	104.4
23	LUMBER	32.4	38.7	45.0	51.3	57.6	63.9	70.2
	SAWDUST	8.8	10.8	12.8	14.8	16.8	18.7	20.7
	RESIDUE	11.1	13.3	15.4	17.6	19.7	21.9	24.1
	GROSS TREE	54.1	64.2	74.3	84.3	94.4	104.5	114.5
24	LUMBER	35.5	42.4	49.3	56.3	63.2	70.1	77.0
	SAWDUST	9.6	11.8	13.9	16.1	18.3	20.5	22.6
	RESIDUE	11.8	14.1	16.3	18.6	20.9	23.2	25.5
	GROSS TREE	58.9	70.0	81.0	92.0	103.0	114.0	125.1
25	LUMBER	38.7	46.3	53.9	61.5	69.0	76.6	84.2
	SAWDUST	10.5	12.8	15.2	17.5	19.9	22.2	24.6
	RESIDUE	12.5	14.9	17.3	19.7	22.1	24.5	26.9
	GROSS TREE	63.9	76.0	88.0	100.0	112.0	124.0	136.0
26	LUMBER	42.1	50.4	58.6	66.9	75.1	83.4	91.6
	SAWDUST	11.3	13.9	16.4	19.0	21.6	24.1	26.7
	RESIDUE	13.2	15.8	18.3	20.8	23.3	25.9	28.4
	GROSS TREE	69.1	82.2	95.3	108.3	121.4	134.4	147.5
27	LUMBER	45.6	54.6	63.5	72.5	81.4	90.4	99.3
	SAWDUST	12.2	15.0	17.8	20.5	23.3	26.0	28.8
	RESIDUE	14.0	16.6	19.3	22.0	24.6	27.3	30.0
	GROSS TREE	74.6	88.7	102.8	117.0	131.1	145.2	159.3
28	LUMBER	49.3	58.9	68.6	78.3	88.0	97.7	107.3
	SAWDUST	13.2	16.2	19.1	22.1	25.1	28.1	31.0
	RESIDUE	14.8	17.6	20.4	23.2	26.0	28.8	31.6
	GROSS TREE	80.2	95.4	110.7	125.9	141.2	156.4	171.7
29	LUMBER	53.0	63.5	73.9	84.3	94.8	105.2	115.6
	SAWDUST	14.2	17.4	20.6	23.7	26.9	30.1	33.3
	RESIDUE	15.6	18.5	21.5	24.4	27.4	30.3	33.3
	GROSS TREE	86.0	102.4	118.8	135.2	151.6	168.0	184.4
30	LUMBER	56.9	68.1	79.4	90.6	101.8	113.0	124.2
	SAWDUST	15.2	18.6	22.0	25.4	28.9	32.3	35.7
	RESIDUE	16.4	19.5	22.6	25.7	28.8	31.9	35.0
	GROSS TREE	92.0	109.6	127.2	144.8	162.5	180.1	197.7

TABLE 11.—PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM PAPER BIRCH BY CIRCULAR MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET)						
		24	32	40	48	56	64	72
10	LUMBER	4.7	5.6	6.5	7.3	8.2	9.1	10.0
	SAWDUST	1.6	2.0	2.3	2.7	3.0	3.4	3.7
	RESIDUE	4.7	5.8	6.9	8.0	9.0	10.1	11.2
	GROSS TREE	11.0	13.3	15.7	18.0	20.3	22.6	24.9
11	LUMBER	5.7	6.9	8.0	9.2	10.3	11.5	12.6
	SAWDUST	1.9	2.4	2.8	3.2	3.6	4.1	4.5
	RESIDUE	5.3	6.5	7.7	8.9	10.1	11.3	12.5
	GROSS TREE	13.0	15.8	18.5	21.3	24.0	26.8	29.5
12	LUMBER	6.9	8.3	9.7	11.2	12.6	14.0	15.5
	SAWDUST	2.3	2.8	3.3	3.8	4.3	4.8	5.3
	RESIDUE	6.1	7.4	8.7	10.0	11.2	12.5	13.8
	GROSS TREE	15.2	18.4	21.7	24.9	28.1	31.4	34.6
13	LUMBER	8.1	9.8	11.6	13.3	15.1	16.8	18.6
	SAWDUST	2.6	3.2	3.8	4.4	5.0	5.6	6.2
	RESIDUE	6.8	8.3	9.7	11.1	12.5	13.9	15.3
	GROSS TREE	17.6	21.3	25.1	28.8	32.6	36.4	40.1
14	LUMBER	9.4	11.5	13.6	15.7	17.8	19.9	21.9
	SAWDUST	3.0	3.7	4.4	5.1	5.8	6.5	7.2
	RESIDUE	7.7	9.2	10.8	12.3	13.8	15.4	16.9
	GROSS TREE	20.1	24.4	28.8	33.1	37.4	41.8	46.1
15	LUMBER	10.8	13.3	15.7	18.2	20.7	23.1	25.6
	SAWDUST	3.4	4.2	5.0	5.9	6.7	7.5	8.3
	RESIDUE	8.6	10.3	11.9	13.6	15.3	17.0	18.7
	GROSS TREE	22.9	27.8	32.7	37.7	42.6	47.6	52.5
16	LUMBER	12.4	15.2	18.0	20.9	23.7	26.6	29.4
	SAWDUST	3.8	4.8	5.7	6.6	7.6	8.5	9.4
	RESIDUE	9.5	11.4	13.2	15.0	16.8	18.7	20.5
	GROSS TREE	25.8	31.4	37.0	42.6	48.2	53.8	59.4
17	LUMBER	14.0	17.2	20.5	23.8	27.0	30.3	33.5
	SAWDUST	4.3	5.4	6.4	7.5	8.5	9.6	10.7
	RESIDUE	10.6	12.6	14.5	16.5	18.5	20.5	22.5
	GROSS TREE	28.9	35.2	41.5	47.8	54.1	60.4	66.7
18	LUMBER	15.7	19.4	23.1	26.8	30.5	34.2	37.9
	SAWDUST	4.8	6.0	7.2	8.4	9.6	10.8	11.9
	RESIDUE	11.7	13.8	16.0	18.1	20.2	22.4	24.5
	GROSS TREE	32.2	39.2	46.3	53.3	60.3	67.4	74.4
19	LUMBER	17.5	21.7	25.8	30.0	34.2	38.3	42.5
	SAWDUST	5.3	6.7	8.0	9.3	10.6	12.0	13.3
	RESIDUE	12.8	15.1	17.5	19.8	22.1	24.4	26.7
	GROSS TREE	35.7	43.5	51.3	59.1	67.0	74.8	82.6
20	LUMBER	19.4	24.1	28.7	33.4	38.0	42.7	47.4
	SAWDUST	5.9	7.4	8.8	10.3	11.8	13.3	14.7
	RESIDUE	14.0	16.5	19.0	21.5	24.0	26.6	29.1
	GROSS TREE	39.4	48.0	56.7	65.3	73.9	82.6	91.2
21	LUMBER	21.4	26.6	31.8	36.9	42.1	47.3	52.5
	SAWDUST	6.5	8.1	9.7	11.4	13.0	14.6	16.2
	RESIDUE	15.3	18.0	20.7	23.4	26.1	28.8	31.5
	GROSS TREE	43.3	52.8	62.3	71.8	81.3	90.8	100.3
22	LUMBER	23.5	29.2	35.0	40.7	46.4	52.1	57.8
	SAWDUST	7.1	8.9	10.7	12.5	14.2	16.0	17.8
	RESIDUE	16.6	19.5	22.4	25.3	28.2	31.1	34.1
	GROSS TREE	47.3	57.7	68.1	78.6	89.0	99.4	109.8
23	LUMBER	25.7	32.0	38.3	44.6	50.9	57.2	63.4
	SAWDUST	7.7	9.7	11.6	13.6	15.6	17.5	19.5
	RESIDUE	18.0	21.2	24.3	27.4	30.5	33.6	36.7
	GROSS TREE	51.6	62.9	74.3	85.7	97.0	108.4	119.7
24	LUMBER	28.0	34.9	41.8	48.7	55.5	62.4	69.3
	SAWDUST	8.4	10.5	12.7	14.8	16.9	19.1	21.2
	RESIDUE	19.5	22.8	26.2	29.5	32.8	36.2	39.5
	GROSS TREE	56.0	68.4	80.7	93.1	105.4	117.8	130.1
25	LUMBER	30.4	37.9	45.4	52.9	60.4	67.9	75.4
	SAWDUST	9.1	11.4	13.7	16.1	18.4	20.7	23.0
	RESIDUE	21.0	24.6	28.2	31.7	35.3	38.9	42.4
	GROSS TREE	60.6	74.0	87.4	100.8	114.2	127.6	141.0
26	LUMBER	32.9	41.1	49.2	57.3	65.5	73.6	81.8
	SAWDUST	9.8	12.3	14.8	17.4	19.9	22.4	24.9
	RESIDUE	22.6	26.4	30.2	34.0	37.8	41.7	45.5
	GROSS TREE	65.5	79.9	94.4	108.9	123.3	137.8	152.2
27	LUMBER	35.5	44.3	53.1	61.9	70.7	79.6	88.4
	SAWDUST	10.6	13.3	16.0	18.7	21.4	24.1	26.8
	RESIDUE	24.3	28.3	32.4	36.4	40.5	44.6	48.6
	GROSS TREE	70.5	86.1	101.6	117.2	132.8	148.4	164.0
28	LUMBER	38.2	47.7	57.2	66.7	76.2	85.7	95.2
	SAWDUST	11.4	14.3	17.2	20.1	23.0	25.9	28.8
	RESIDUE	26.0	30.3	34.6	38.9	43.2	47.6	51.9
	GROSS TREE	75.7	92.4	109.2	125.9	142.6	159.4	176.1
29	LUMBER	41.0	51.2	61.5	71.7	81.9	92.1	102.3
	SAWDUST	12.2	15.3	18.4	21.6	24.7	27.8	30.9
	RESIDUE	27.8	32.3	36.9	41.5	46.1	50.7	55.3
	GROSS TREE	81.0	99.0	116.9	134.9	152.8	170.8	188.7
30	LUMBER	43.9	54.9	65.8	76.8	87.7	98.7	109.7
	SAWDUST	13.0	16.4	19.7	23.1	26.4	29.8	33.1
	RESIDUE	29.6	34.5	39.3	44.2	49.0	53.9	58.8
	GROSS TREE	86.6	105.8	125.0	144.2	163.4	182.6	201.8

TABLE 12.--PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM YELLOW BIRCH BY BAND MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET)						
		24	32	40	48	56	64	72
10	LUMBER	3.9	4.3	4.7	5.1	5.5	5.9	6.3
	SAWDUST	0.9	0.9	1.0	1.0	1.0	1.1	1.1
	RESIDUE	4.7	5.8	7.0	8.1	9.3	10.5	11.6
	GROSS TREE	9.8	11.8	13.9	16.0	18.1	20.2	22.2
11	LUMBER	5.1	5.8	6.5	7.2	7.8	8.5	9.2
	SAWDUST	1.0	1.1	1.2	1.3	1.4	1.5	1.6
	RESIDUE	5.2	6.4	7.6	8.8	10.0	11.3	12.5
	GROSS TREE	11.7	14.2	16.6	19.0	21.5	23.9	26.3
12	LUMBER	6.4	7.4	8.4	9.4	10.4	11.4	12.4
	SAWDUST	1.2	1.4	1.5	1.7	1.9	2.0	2.2
	RESIDUE	5.7	7.0	8.3	9.6	10.9	12.1	13.4
	GROSS TREE	13.9	16.7	19.5	22.3	25.1	28.0	30.8
13	LUMBER	7.8	9.1	10.4	11.8	13.1	14.4	15.8
	SAWDUST	1.4	1.7	1.9	2.1	2.3	2.6	2.8
	RESIDUE	6.4	7.7	9.1	10.4	11.7	13.1	14.4
	GROSS TREE	16.2	19.4	22.7	25.9	29.2	32.4	35.7
14	LUMBER	9.3	11.0	12.7	14.4	16.1	17.8	19.5
	SAWDUST	1.7	2.0	2.3	2.5	2.8	3.1	3.4
	RESIDUE	7.0	8.5	9.9	11.3	12.7	14.1	15.5
	GROSS TREE	18.7	22.4	26.1	29.8	33.5	37.2	40.9
15	LUMBER	10.9	13.0	15.1	17.2	19.3	21.3	23.4
	SAWDUST	1.9	2.3	2.6	3.0	3.4	3.8	4.1
	RESIDUE	7.8	9.3	10.7	12.2	13.7	15.2	16.7
	GROSS TREE	21.4	25.6	29.8	34.0	38.2	42.4	46.5
16	LUMBER	12.6	15.1	17.6	20.1	22.7	25.2	27.7
	SAWDUST	2.2	2.6	3.1	3.5	4.0	4.4	4.9
	RESIDUE	8.5	10.1	11.7	13.3	14.8	16.4	18.0
	GROSS TREE	24.3	29.0	33.7	38.4	43.1	47.9	52.6
17	LUMBER	14.4	17.4	20.3	23.3	26.3	29.2	32.2
	SAWDUST	2.4	3.0	3.5	4.0	4.6	5.1	5.7
	RESIDUE	9.3	11.0	12.7	14.3	16.0	17.7	19.3
	GROSS TREE	27.3	32.6	37.9	43.2	48.4	53.7	59.0
18	LUMBER	16.4	19.8	23.2	26.7	30.1	33.5	37.0
	SAWDUST	2.7	3.3	4.0	4.6	5.2	5.9	6.5
	RESIDUE	10.2	12.0	13.7	15.5	17.3	19.0	20.8
	GROSS TREE	30.6	36.5	42.3	48.2	54.1	59.9	65.8
19	LUMBER	18.4	22.4	26.3	30.2	34.2	38.1	42.0
	SAWDUST	3.0	3.7	4.5	5.2	5.9	6.7	7.4
	RESIDUE	11.1	13.0	14.8	16.7	18.6	20.4	22.3
	GROSS TREE	34.0	40.5	47.0	53.5	60.0	66.5	73.0
20	LUMBER	20.6	25.1	29.5	34.0	38.4	42.9	47.4
	SAWDUST	3.3	4.2	5.0	5.8	6.7	7.5	8.3
	RESIDUE	12.1	14.1	16.0	18.0	20.0	21.9	23.9
	GROSS TREE	37.7	44.8	52.0	59.1	66.3	73.4	80.6
21	LUMBER	22.9	27.9	32.9	37.9	42.9	48.0	53.0
	SAWDUST	3.7	4.6	5.6	6.5	7.4	8.4	9.3
	RESIDUE	13.1	15.2	17.3	19.3	21.4	23.5	25.6
	GROSS TREE	41.5	49.3	57.2	65.0	72.9	80.7	88.6
22	LUMBER	25.3	30.9	36.5	42.1	47.7	53.3	58.9
	SAWDUST	4.0	5.1	6.1	7.2	8.2	9.3	10.4
	RESIDUE	14.2	16.4	18.6	20.7	22.9	25.1	27.3
	GROSS TREE	45.5	54.0	62.6	71.2	79.8	88.3	96.9
23	LUMBER	27.8	34.0	40.2	46.4	52.6	58.8	65.0
	SAWDUST	4.4	5.6	6.7	7.9	9.1	10.3	11.4
	RESIDUE	15.3	17.6	19.9	22.2	24.5	26.8	29.1
	GROSS TREE	49.6	59.0	68.3	77.7	87.0	96.3	105.7
24	LUMBER	30.4	37.2	44.1	50.9	57.8	64.6	71.4
	SAWDUST	4.8	6.1	7.4	8.7	10.0	11.3	12.6
	RESIDUE	16.5	18.9	21.3	23.8	26.2	28.6	31.1
	GROSS TREE	54.0	64.1	74.3	84.4	94.5	104.7	114.8
25	LUMBER	33.1	40.6	48.1	55.6	63.1	70.6	78.1
	SAWDUST	5.2	6.6	8.0	9.5	10.9	12.3	13.7
	RESIDUE	17.7	20.2	22.8	25.4	27.9	30.5	33.1
	GROSS TREE	58.6	69.5	80.5	91.5	102.4	113.4	124.3
26	LUMBER	35.9	44.1	52.3	60.5	68.7	76.9	85.1
	SAWDUST	5.6	7.2	8.7	10.3	11.8	13.4	15.0
	RESIDUE	18.9	21.6	24.3	27.0	29.7	32.4	35.1
	GROSS TREE	63.3	75.1	87.0	98.8	110.6	122.4	134.3
27	LUMBER	38.9	47.8	56.7	65.6	74.5	83.5	92.4
	SAWDUST	6.1	7.7	9.4	11.1	12.8	14.5	16.2
	RESIDUE	20.3	23.1	25.9	28.8	31.6	34.5	37.3
	GROSS TREE	68.2	81.0	93.7	106.4	119.1	131.8	144.6
28	LUMBER	41.9	51.6	61.2	70.9	80.6	90.2	99.9
	SAWDUST	6.5	8.3	10.2	12.0	13.9	15.7	17.5
	RESIDUE	21.6	24.6	27.6	30.6	33.6	36.6	39.6
	GROSS TREE	73.3	87.0	100.6	114.3	128.0	141.6	155.3
29	LUMBER	45.1	55.5	65.9	76.4	86.8	97.3	107.7
	SAWDUST	7.0	9.0	11.0	12.9	14.9	16.9	18.9
	RESIDUE	23.0	26.2	29.3	32.5	35.6	38.7	41.9
	GROSS TREE	78.6	93.3	107.9	122.5	137.1	151.7	166.4
30	LUMBER	48.3	59.6	70.8	82.1	93.3	104.5	115.8
	SAWDUST	7.5	9.6	11.8	13.9	16.0	18.2	20.3
	RESIDUE	24.5	27.8	31.1	34.4	37.7	41.0	44.3
	GROSS TREE	84.1	99.7	115.4	131.0	146.6	162.2	177.8

TABLE 13.—PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM YELLOW BIRCH BY CIRCULAR MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET) 24	32	40	48	56	64	72
10	LUMBER	3.8	5.1	6.3	7.6	8.9	10.2	11.4
	SAWDUST	1.6	2.0	2.4	2.9	3.3	3.7	4.1
	RESIDUE	4.7	5.8	7.0	8.1	9.3	10.5	11.6
	GROSS TREE	9.8	11.8	13.9	16.0	18.1	20.2	22.2
11	LUMBER	4.9	6.4	7.8	9.3	10.8	12.2	13.7
	SAWDUST	1.9	2.4	2.8	3.3	3.8	4.3	4.8
	RESIDUE	5.2	6.4	7.6	8.8	10.0	11.3	12.5
	GROSS TREE	11.7	14.2	16.6	19.0	21.5	23.9	26.3
12	LUMBER	6.2	7.8	9.5	11.1	12.8	14.5	16.1
	SAWDUST	2.2	2.7	3.3	3.8	4.4	4.9	5.5
	RESIDUE	5.7	7.0	8.3	9.6	10.9	12.1	13.4
	GROSS TREE	13.9	16.7	19.5	22.3	25.1	28.0	30.8
13	LUMBER	7.6	9.4	11.3	13.2	15.0	16.9	18.8
	SAWDUST	2.6	3.2	3.8	4.4	5.0	5.6	6.2
	RESIDUE	6.4	7.7	9.1	10.4	11.7	13.1	14.4
	GROSS TREE	16.2	19.4	22.7	25.9	29.2	32.4	35.7
14	LUMBER	9.0	11.1	13.2	15.3	17.4	19.5	21.6
	SAWDUST	2.9	3.6	4.3	5.0	5.7	6.4	7.0
	RESIDUE	7.0	8.5	9.9	11.3	12.7	14.1	15.5
	GROSS TREE	18.7	22.4	26.1	29.8	33.5	37.2	40.9
15	LUMBER	10.6	13.0	15.3	17.7	20.0	22.4	24.7
	SAWDUST	3.3	4.1	4.9	5.6	6.4	7.2	7.9
	RESIDUE	7.8	9.3	10.7	12.2	13.7	15.2	16.7
	GROSS TREE	21.4	25.6	29.8	34.0	38.2	42.4	46.5
16	LUMBER	12.3	14.9	17.5	20.2	22.8	25.4	28.0
	SAWDUST	3.8	4.6	5.5	6.3	7.2	8.0	8.9
	RESIDUE	8.5	10.1	11.7	13.3	14.8	16.4	18.0
	GROSS TREE	24.3	29.0	33.7	38.4	43.1	47.9	52.6
17	LUMBER	14.1	17.0	19.9	22.8	25.7	28.6	31.5
	SAWDUST	4.2	5.2	6.1	7.1	8.0	8.9	9.9
	RESIDUE	9.3	11.0	12.7	14.3	16.0	17.7	19.3
	GROSS TREE	27.3	32.6	37.9	43.2	48.4	53.7	59.0
18	LUMBER	16.0	19.2	22.4	25.6	28.8	32.0	35.2
	SAWDUST	4.7	5.8	6.8	7.8	8.9	9.9	11.0
	RESIDUE	10.2	12.0	13.7	15.5	17.3	19.0	20.8
	GROSS TREE	30.6	36.5	42.3	48.2	54.1	59.9	65.8
19	LUMBER	18.1	21.6	25.1	28.6	32.1	35.7	39.2
	SAWDUST	5.2	6.4	7.5	8.7	9.8	10.9	12.1
	RESIDUE	11.1	13.0	14.8	16.7	18.6	20.4	22.3
	GROSS TREE	34.0	40.5	47.0	53.5	60.0	66.5	73.0
20	LUMBER	20.2	24.0	27.9	31.8	35.6	39.5	43.3
	SAWDUST	5.8	7.0	8.3	9.5	10.8	12.0	13.3
	RESIDUE	12.1	14.1	16.0	18.0	20.0	21.9	23.9
	GROSS TREE	37.7	44.8	52.0	59.1	66.3	73.4	80.6
21	LUMBER	22.4	26.6	30.8	35.1	39.3	43.5	47.7
	SAWDUST	6.4	7.7	9.1	10.4	11.8	13.2	14.5
	RESIDUE	13.1	15.2	17.3	19.3	21.4	23.5	25.6
	GROSS TREE	41.5	49.3	57.2	65.0	72.9	80.7	88.6
22	LUMBER	24.8	29.4	33.9	38.5	43.1	47.7	52.2
	SAWDUST	7.0	8.4	9.9	11.4	12.9	14.4	15.8
	RESIDUE	14.2	16.4	18.6	20.7	22.9	25.1	27.3
	GROSS TREE	45.5	54.0	62.6	71.2	79.8	88.3	96.9
23	LUMBER	27.2	32.2	37.2	42.1	47.1	52.1	57.0
	SAWDUST	7.6	9.2	10.8	12.4	14.0	15.6	17.2
	RESIDUE	15.3	17.6	19.9	22.2	24.5	26.8	29.1
	GROSS TREE	49.6	59.0	68.3	77.7	87.0	96.3	105.7
24	LUMBER	29.8	35.2	40.6	45.9	51.3	56.7	62.0
	SAWDUST	8.3	10.0	11.7	13.5	15.2	16.9	18.6
	RESIDUE	16.5	18.9	21.3	23.8	26.2	28.6	31.1
	GROSS TREE	54.0	64.1	74.3	84.4	94.5	104.7	114.8
25	LUMBER	32.5	38.3	44.1	49.9	55.7	61.4	67.2
	SAWDUST	8.9	10.8	12.7	14.5	16.4	18.3	20.1
	RESIDUE	17.7	20.2	22.8	25.4	27.9	30.5	33.1
	GROSS TREE	58.6	69.5	80.5	91.5	102.4	113.4	124.3
26	LUMBER	35.3	41.5	47.7	54.0	60.2	66.4	72.7
	SAWDUST	9.7	11.7	13.7	15.7	17.7	19.7	21.7
	RESIDUE	18.9	21.6	24.3	27.0	29.7	32.4	35.1
	GROSS TREE	63.3	75.1	87.0	98.8	110.6	122.4	134.3
27	LUMBER	38.2	44.9	51.6	58.2	64.9	71.6	78.3
	SAWDUST	10.4	12.6	14.7	16.9	19.0	21.2	23.3
	RESIDUE	20.3	23.1	25.9	28.8	31.6	34.5	37.3
	GROSS TREE	68.2	81.0	93.7	106.4	119.1	131.8	144.6
28	LUMBER	41.2	48.4	55.5	62.7	69.8	77.0	84.1
	SAWDUST	11.2	13.5	15.8	18.1	20.4	22.7	25.0
	RESIDUE	21.6	24.6	27.6	30.6	33.6	36.6	39.6
	GROSS TREE	73.3	87.0	100.6	114.3	128.0	141.6	155.3
29	LUMBER	44.3	52.0	59.6	67.3	74.9	82.5	90.2
	SAWDUST	12.0	14.4	16.9	19.4	21.8	24.3	26.7
	RESIDUE	23.0	26.2	29.3	32.5	35.6	38.7	41.9
	GROSS TREE	78.6	93.3	107.9	122.5	137.1	151.7	166.4
30	LUMBER	47.5	55.7	63.8	72.0	80.2	88.3	96.5
	SAWDUST	12.8	15.4	18.0	20.7	23.3	25.9	28.5
	RESIDUE	24.5	27.8	31.1	34.4	37.7	41.0	44.3
	GROSS TREE	84.1	99.7	115.4	131.0	146.6	162.2	177.8

TABLE 14.—PREDICTED YIELDS OF SAWMILL PRODUCTS OBTAINED FROM BASSWOOD BY BAND MILLS (CUBIC FEET)

DBH (INCHES)	PRODUCT	MERCHANTABLE HEIGHT (FEET)						
		24	32	40	48	56	64	72
10	LUMBER	2.7	5.4	8.1	10.7	13.4	16.0	18.7
	SAWDUST	0.5	1.0	1.6	2.2	2.7	3.3	3.8
	RESIDUE	4.3	4.5	4.7	5.0	5.2	5.4	5.6
	GROSS TREE	7.2	11.0	14.7	18.5	22.2	25.9	29.7
11	LUMBER	4.1	6.9	9.7	12.5	15.3	18.1	20.9
	SAWDUST	0.7	1.3	1.9	2.4	3.0	3.6	4.2
	RESIDUE	4.9	5.3	5.6	5.9	6.3	6.6	6.9
	GROSS TREE	9.6	13.6	17.5	21.5	25.5	29.5	33.4
12	LUMBER	5.6	8.5	11.5	14.4	17.4	20.3	23.3
	SAWDUST	0.9	1.6	2.2	2.8	3.4	4.0	4.6
	RESIDUE	5.6	6.1	6.5	7.0	7.4	7.9	8.3
	GROSS TREE	12.1	16.4	20.6	24.9	29.1	33.3	37.6
13	LUMBER	7.2	10.3	13.4	16.5	19.6	22.7	25.8
	SAWDUST	1.2	1.8	2.5	3.1	3.7	4.4	5.0
	RESIDUE	6.4	7.0	7.6	8.1	8.7	9.3	9.8
	GROSS TREE	14.9	19.4	24.0	28.5	33.0	37.5	42.1
14	LUMBER	8.9	12.2	15.5	18.8	22.0	25.3	28.6
	SAWDUST	1.5	2.2	2.8	3.5	4.1	4.8	5.5
	RESIDUE	7.2	7.9	8.7	9.4	10.1	10.8	11.5
	GROSS TREE	17.9	22.7	27.6	32.4	37.2	42.1	46.9
15	LUMBER	10.7	14.2	17.7	21.2	24.7	28.1	31.6
	SAWDUST	1.8	2.5	3.2	3.9	4.6	5.3	5.9
	RESIDUE	8.1	9.0	9.8	10.7	11.5	12.4	13.3
	GROSS TREE	21.1	26.3	31.5	36.6	41.8	46.9	52.1
16	LUMBER	12.7	16.4	20.1	23.8	27.5	31.1	34.8
	SAWDUST	2.1	2.9	3.6	4.3	5.0	5.7	6.5
	RESIDUE	9.1	10.1	11.1	12.1	13.1	14.1	15.2
	GROSS TREE	24.6	30.1	35.6	41.1	46.6	52.2	57.7
17	LUMBER	14.8	18.7	22.6	26.5	30.4	34.3	38.2
	SAWDUST	2.5	3.2	4.0	4.7	5.5	6.3	7.0
	RESIDUE	10.1	11.3	12.4	13.6	14.8	16.0	17.2
	GROSS TREE	28.2	34.1	40.0	45.9	51.8	57.7	63.6
18	LUMBER	17.1	21.2	25.3	29.5	33.6	37.7	41.8
	SAWDUST	2.9	3.6	4.4	5.2	6.0	6.8	7.6
	RESIDUE	11.1	12.5	13.9	15.2	16.6	17.9	19.3
	GROSS TREE	32.1	38.4	44.7	51.0	57.3	63.6	69.9
19	LUMBER	19.4	23.8	28.2	32.6	36.9	41.3	45.7
	SAWDUST	3.2	4.1	4.9	5.7	6.6	7.4	8.2
	RESIDUE	12.3	13.8	15.4	16.9	18.5	20.0	21.6
	GROSS TREE	36.2	42.9	49.7	56.4	63.1	69.8	76.5
20	LUMBER	21.9	26.6	31.2	35.8	40.4	45.1	49.7
	SAWDUST	3.7	4.5	5.4	6.3	7.1	8.0	8.9
	RESIDUE	13.5	15.2	17.0	18.7	20.5	22.2	24.0
	GROSS TREE	40.6	47.7	54.9	62.0	69.2	76.4	83.5
21	LUMBER	24.6	29.5	34.3	39.2	44.1	49.0	53.9
	SAWDUST	4.1	5.0	5.9	6.8	7.7	8.7	9.6
	RESIDUE	14.7	16.7	18.6	20.6	22.5	24.5	26.5
	GROSS TREE	45.1	52.7	60.4	68.0	75.6	83.3	90.9
22	LUMBER	27.3	32.5	37.7	42.8	48.0	53.2	58.4
	SAWDUST	4.5	5.5	6.5	7.4	8.4	9.3	10.3
	RESIDUE	16.0	18.2	20.4	22.6	24.7	26.9	29.1
	GROSS TREE	49.9	58.0	66.1	74.2	82.4	90.5	98.6
23	LUMBER	30.2	35.7	41.1	46.6	52.1	57.6	63.0
	SAWDUST	5.0	6.0	7.0	8.0	9.0	10.0	11.0
	RESIDUE	17.4	19.8	22.2	24.6	27.0	29.4	31.8
	GROSS TREE	54.9	63.5	72.1	80.8	89.4	98.0	106.7
24	LUMBER	33.2	39.0	44.8	50.5	56.3	62.1	67.9
	SAWDUST	5.5	6.6	7.6	8.7	9.7	10.8	11.8
	RESIDUE	18.8	21.5	24.1	26.8	29.4	32.1	34.7
	GROSS TREE	60.1	69.3	78.4	87.6	96.8	105.9	115.1
25	LUMBER	36.3	42.4	48.5	54.6	60.7	66.8	72.9
	SAWDUST	6.0	7.1	8.2	9.4	10.5	11.6	12.7
	RESIDUE	20.3	23.2	26.1	29.0	31.9	34.8	37.7
	GROSS TREE	65.5	75.3	85.0	94.7	104.5	114.2	123.9
26	LUMBER	39.6	46.0	52.5	58.9	65.3	71.8	78.2
	SAWDUST	6.6	7.7	8.9	10.0	11.2	12.4	13.5
	RESIDUE	21.9	25.0	28.2	31.3	34.5	37.7	40.8
	GROSS TREE	71.2	81.5	91.8	102.1	112.4	122.8	133.1
27	LUMBER	43.0	49.8	56.6	63.3	70.1	76.9	83.7
	SAWDUST	7.1	8.4	9.6	10.8	12.0	13.2	14.4
	RESIDUE	23.5	26.9	30.3	33.8	37.2	40.6	44.1
	GROSS TREE	77.1	88.0	98.9	109.8	120.7	131.7	142.6
28	LUMBER	46.5	53.7	60.8	67.9	75.1	82.2	89.4
	SAWDUST	7.7	9.0	10.3	11.5	12.8	14.1	15.3
	RESIDUE	25.2	28.9	32.6	36.3	40.0	43.7	47.4
	GROSS TREE	83.2	94.7	106.3	117.8	129.4	140.9	152.4
29	LUMBER	50.2	57.7	65.2	72.7	80.2	87.7	95.3
	SAWDUST	8.3	9.7	11.0	12.3	13.6	15.0	16.3
	RESIDUE	26.9	30.9	34.9	38.9	42.9	46.9	50.9
	GROSS TREE	89.5	101.7	113.9	126.1	138.3	150.5	162.7
30	LUMBER	53.9	61.8	69.7	77.6	85.5	93.4	101.3
	SAWDUST	9.0	10.3	11.7	13.1	14.5	15.9	17.3
	RESIDUE	28.7	33.0	37.3	41.6	45.9	50.2	54.5
	GROSS TREE	96.1	108.9	121.8	134.7	147.5	160.4	173.3

Sawmill Residue Volume

A portion of the sawmill residue volume is not useable because of rot; the remainder is useable for chips. Averages for rot in the sample trees are:

Species	*Average rot (percent)*
Northern red oak	4
White oak	2
Black oak	2
Chestnut oak	4
Red maple	3
Sugar maple	3
Yellow-poplar	2
Yellow birch	4
Paper birch	5
Basswood	4

If the percentage of rot in your area is greater than the percentages that we calculated, the volumes of lumber and sawdust will decrease and the volume of sawmill residue will increase.

Weight-Volume Relationships

Chips and sawdust are not marketed on a cubic-foot basis; however conversion to weight is possible if the density of the wood is known. Species averages are shown below *(U.S. Forest Products Laboratory 1974)*, but it should be recognized that actual density varies by location. To obtain a better estimate of density for a given location, wood samples should be collected and standard techniques should be used.

Species	*Density*[4] *(lb/ft³)*
Northern red oak	34.9
White oak	37.4
Black oak	34.9
Chestnut oak	35.5
Red maple	30.6
Sugar maple	34.9
Yellow-poplar	25.0
Yellow birch	34.3
Paper birch	30.0
Basswood	20.0

Phillips and others *(1974)* predicted recovery percentages for lumber, chippable residue, bark residue, and sawdust—on a weight basis—for 40 of the 224 black oak trees that were used for this study. With the exception of bark residue, we have predicted similar recovery percentages on a cubic-foot volume basis (table 15). We adjusted the percentages in Phillips' report so that bark residue could be removed from the table.

Table 15.—*Percentage recovery of lumber, chippable residue, and sawdust from 40 black oak trees, computed by weight and by volume*

Dbh	Number of trees	Lumber		Chippable residue		Sawdust	
		Weight	Volume	Weight	Volume	Weight	Volume
12	2	59	58	29	31	12	10
13	2	62	64	24	25	14	11
14	1	58	59	28	31	14	10
15	3	61	57	26	32	13	10
16	5	58	56	29	34	13	10
17	5	64	63	23	26	13	11
18	4	60	56	27	35	13	10
19	0	—	—	—	—	—	—
20	3	66	65	22	24	12	11
21	4	65	64	22	25	13	11
22	5	66	65	22	25	12	10
23	1	70	73	18	16	11	11
24	1	66	68	21	21	12	11
25	2	68	66	20	24	12	10
26	2	69	66	20	23	12	10
Weighted average		65	64	24	26	12	10

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[4] Based on specific gravity at ovendry weight and green volume.

The small differences between figures for weight and volume were probably caused by differences in kerf or lumber sizing between the actual and the estimated sizes. We believe that the closeness of these recovery percentages indicates that the weight of chippable residue and sawdust can be successfully estimated with the cubic-foot volume equations or tables.

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Height of Tallest Saplings in 10-year-old Appalachian Hardwood Clearcuts

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1977
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The Author

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ABSTRACT

Stem characteristics, mainly height, of the tallest hardwood saplings in 10-year-old circular clearcut openings were evaluated for several Appalachian hardwoods in West Virginia. Heights of the tallest saplings were not influenced by cardinal directions on two oak sites. Saplings were taller near the center of 150-, 200-, and 250-foot openings than saplings in the center of the 50- and 100-foot openings. Saplings in the larger openings (150- to 250-foot) were significantly taller near the opening center compared to the tallest saplings along the border of the same size openings. For small openings (100-foot or less), the border effect was present throughout the openings.

Height of Tallest Saplings in 10-year-old Appalachian Hardwood Clearcuts

WE HAVE INFORMATION from a West Virginia study that may be helpful in answering questions about the effect of size of clearcut openings on the heights of dominant-codominant hardwood reproduction.

Generally, hardwood reproduction near the borders of clearcut openings is not as tall as that in the center of the openings *(Smith 1963)*. However, Tryon and Trimble *(1969)* reported that the height of dominant-codominant Appalachian hardwood reproduction in 14-year-old 1/4- and 1/2-acre openings did not differ, and stems including the intolerants were capable of growing well in openings as small as 1/4-acre for at least 15 years. Minckler and Woerheide *(1965)* evaluated hardwood reproduction in the Central States and reported that the north and central portions of 10-year-old clearcut openings had taller trees. However, Trimble and Tryon *(1969)* reported no difference in height of dominant-codominant stems for any cardinal direction quadrant.

For upland hardwoods in the Central States, opening size did not affect reproduction growth 2 years after cutting *(Sander and Clark 1971)*. They reported an edge or border effect on all circular openings (1/8- to 5-acres). However, Clark and Watt *(1971)* noted that the smaller openings, less than 1/2-acre in size, had a much greater percentage of area that was influenced by the border. They indicated that the width of the border effect was likely to be greater than 10 feet and less than 30 feet.

To provide additional information about height of reproduction, we evaluated several characteristics, mainly height, of the tallest saplings in 10-year-old Appalachian hardwood clearcut openings.

STUDY AREA

The study was made on the Fernow Experimental Forest near Parsons, West Virginia. Data were collected on two oak sites—site index 60 and site index 75. The area had been heavily cut to remove the best trees in 1905 to 1910. Average annual rainfall for this locale usually varies from 55 to 60 inches. Soils are largely Calvin and DeKalb channery silt loams averaging 30 inches depth to bedrock.

All stands were unmanaged and well stocked at the time the study began in 1965. These stands were dominated by sugar maple, yellow-poplar, red oak, black cherry, basswood, beech, and sweet birch trees on the better sites. On the fair sites, chestnut oak, red oak, red maple, sweet birch, black gum, sassafras, and sourwood were dominant. On the better sites, the heights of dominant-codominant border trees averaged about 90 feet, on the fair sites about 65 feet. Most of the sawtimber-size trees were second growth, 55 to 60 years old; however, there were some old residuals from the early logging in 1905 to 1910.

METHODS

For the study we used circular clearcut openings 50, 100, 150, 200, and 250 feet in diameter on the good sites and 50, 150, and 250 feet in diameter on the fair sites. There were three replications of each opening size. The 50-foot openings involved the removal of two or three sawtimber-size trees, resembling an individual-tree selection or group-selection cutting practice. The 250-foot openings were more than 1 acre in size and provided the effect of a clearcut.

Circular plot diameter	*Acres*	*Number of openings*	
		Good site	*Fair site*
(feet)		*SI 75*	*SI 60*
50	0.045	3	3
100	.180	3	0
150	.406	3	3
200	.721	3	0
250	1.127	3	3

All trees 5 inches diameter breast height (dbh) and larger were cut. Stems 1.0 to 4.9 inches dbh were basal-sprayed, using 2,4,5-T at 16 pounds acid equivalent per 100 gallons (ahg) mixed with diesel oil. Also, all cut stumps were sprayed with this herbicide mixture. This herbicide treatment was used to reduce sprouting.

For sampling purposes, radial transects in the four cardinal directions were used in selecting study stems. Successive 25-foot long, 4-foot wide sampling plots were established along the transects. Thus, a 50-foot diameter opening had one 25-foot sample plot per cardinal direction or four sample plots per opening. A 250-foot diameter opening had five 25-foot sampling plots per cardinal direction or 20 sample plots per opening. The 25-foot sample plots started at the opening center (sample plot 1) and progressed toward the opening border (fig. 1).

Data analyses and comparisons were made on the heights of the tallest sapling in 10-year-old clearcuts.

The tallest dominant-codominant sapling was selected within each 25-foot sample plot regardless of species. Occasionally a sapling adjacent to the sample plot was selected because it was dominating saplings on the sample plot. Data recorded for the tallest sapling were: species, dbh, total height, crown class, and potential for a sawlog crop tree. Aspect, slope position, and slope percent were variable among the openings, and we did not have sufficient information to analyze these data. Data were subjected to analysis of variance techniques and tested for significant differences at the 5-percent level.

RESULTS

Sapling Heights

Cardinal directions.—Statistical analyses indicated that the height of tallest saplings did not differ significantly by direction for the good or fair sites.

Sapling heights by opening size.—The tallest saplings ranged in height from an average of about 17 feet to more than 29 feet on the good sites and about 16 to 32 feet on the fair sites. We found significant differences in sapling heights among the various opening sizes (table 1). Saplings in the center of 50- and 100-foot openings on the good sites were significantly shorter than saplings growing in the center of 150-, 200-, and 250-foot openings.

A similar result was found on the fair sites: saplings in the center of 50-foot openings were

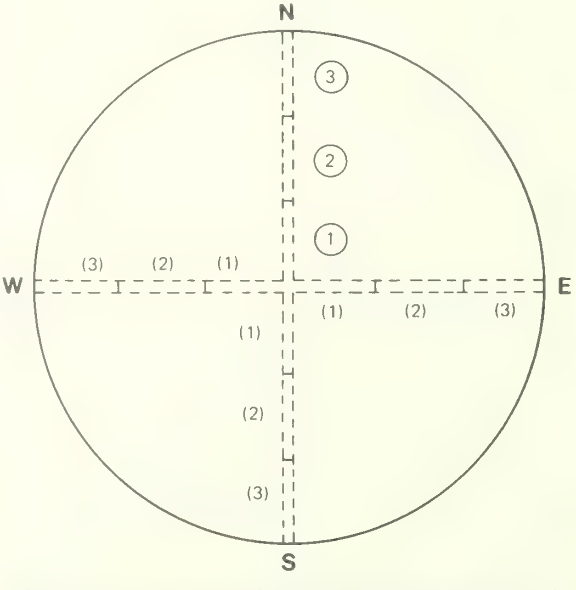

Figure 1.—Schematic of sampling scheme for a 100-foot-diameter opening. Numbers 1, 2, 3 show sample plots.

Table 1.—*Sapling height analyses, in feet*

25-foot sample plots	Opening size							
	Good site					Fair site		
	50	100	150	200	250	50	150	250
AVERAGE HEIGHT TALLEST SAPLINGS BY 25-FOOT PLOTS FOR EACH OPENING SIZE AND SITE CLASS								
1 (center)	16.7a[1]	19.2a	25.5b	27.2b	26.5b	16.2a	30.1b	30.9b
2	—	20.9a	23.5ac	26.1bc	29.5b	—	30.8a	30.2a
3	—	—	20.7a	25.0b	29.3b	—	24.6a	32.2b
4	—	—	—	25.4a	28.4a	—	—	29.6
5 (border)	—	—	—	—	21.0	—	—	24.4
AVERAGE SAPLING HEIGHTS ALONG THE BORDER OF EACH SIZE OPENING								
	16.7a	20.9b	20.7b	25.4b	21.0b	16.2a	24.6a	24.4a

[1] For each site, means in same row identified by the same letter are not significantly different.

significantly shorter than saplings in the center of the 150- and 250-foot openings. These results indicate a border effect, as the saplings in the center of the 50- and 100-foot openings were influenced by the opening perimeter.

We compared the heights of saplings along the borders of the different size openings. For the good sites, tallest saplings in the 50-foot openings were significantly shorter than the tallest saplings along the borders of 100- to 250-foot openings (17 versus 21 feet plus). A similar trend was observed on the fair site, but the data were not quite significant (table 1).

Also, saplings on both the good and fair sites were significantly taller (5 to 6 feet) near the opening centers than along the borders of 150- and 250-foot openings. Saplings in the 200-foot openings were also taller near the opening centers than along the borders, but the difference was not significant. However, the saplings along the borders of 100-foot openings on the good sites were slightly taller than those established near the opening centers, indicating that the border effect is present throughout the smaller openings (table 2).

Table 2.—*Average sapling heights for plot center versus border within same size opening, in feet*

Opening size (feet)	Good site[1]		Fair site	
	Plot center	Border edge	Plot center	Border edge
50	16.7	—	15.8	—
100	19.2a	20.9a	—	—
150	25.5a	20.7b	30.1a	24.6b
200	27.2a	25.4a	—	—
250	26.5a	21.0b	30.9a	24.4b

[1] For each site, means in same row identified by the same letter are not significantly different.

Additional Tallest Tree Characteristics

For the good sites, after 10 years, about 81 percent of the tallest saplings were seedling-origin stems, and this was expected because a herbicide treatment was used to reduce sprouting. However, only about 60 percent of the stems on the fair site were of seedling origin.

Stem diameters (dbh) averaged between 2.0 and 2.7 inches for the tallest saplings in 100- to 250-foot openings. The tallest saplings in the 50-foot openings ranged from 1.2 to 1.5 inches dbh (table 3). For both the good and fair sites, about 90 percent of the tallest saplings were potential sawlog crop trees. Species such as American chestnut, striped maple, and pin cherry were not considered as potential crop trees.

On the good sites, in the 50-, 100-, and 150-foot openings, sugar maple saplings were the tallest stems on about 50 percent of these sample plots. For the 200- and 250-foot openings, black locust and pin cherry accounted for about 45 percent of the tallest saplings. On the fair sites, American chestnut, red maple, sassafras, and pin cherry were frequently the tallest saplings. Several of these taller saplings averaged 25 feet tall and were at least 2.5 inches dbh—pin cherry, black locust, yellow-poplar, and Fraser magnolia on the good sites; and Fraser magnolia, pin cherry, American chestnut, and red maple on the fair sites.

Table 3.—***Stem characteristics for tallest saplings within each size opening by site class—excluding American chestnut, striped maple, and pin cherry***

Opening size (feet)	Height		Dbh		Potential crop trees
	Seedling origin	Sprout origin	Seedling origin	Sprout origin	
	Feet	*Feet*	*Inches*	*Inches*	*Pct.*
			GOOD SITE		
50	17.1 (6)[a]	14.6 (1)	1.2	1.3	75 (5)
100	19.9 (14)	16.9 (3)	1.6	1.3	100 (17)
150	23.2 (25)	22.3 (5)	2.0	1.9	96 (29)
200	25.6 (35)	27.8 (11)	2.2	2.7	95 (44)
250	27.0 (48)	29.1 (9)	2.6	3.2	86 (49)
			FAIR SITE		
50	15.6 (8)	17.4 (4)	1.2	1.2	100 (12)
150	26.4 (11)	26.6 (23)	2.5	2.9	85 (29)
250	29.4 (44)	29.8 (16)	2.7	2.9	85 (51)

[a] Figures in parentheses indicate number of samples.

We also examined the height and dbh of the same species for a variety of opening sizes. On the good site, the heights of sugar maple saplings ranged from about 18 to 24 feet for all openings. The average dbh for sugar maple saplings was erratic, 1.4 to 2.0 for the smaller openings and 1.6 for the largest openings. Of course, the number of sugar maple saplings sampled was much higher in the smaller openings than in the larger openings, as expected.

The height growth of the tallest yellow-poplar and black cherry saplings was strongly influenced by opening size. Height averaged 17 feet or less in 100-foot openings and about 28 feet in 250-foot openings. Average dbh for yellow-poplar ranged from about 2.5 for the 100-foot openings to 3.3 inches for the 250-foot openings. Black cherry averaged 2.6 inches dbh for the 250-foot openings.

On the fair sites, red maple averaged about 20 feet in height and 1.6 inches dbh for the 50-foot openings to about 30 feet and at least 3 inches dbh for the 250-foot openings. Similarly, the height of sassafras saplings ranged from about 15 feet in height and 1.1 inch dbh on 50-foot openings to 24 feet and about 2 inches dbh on the 150- and 250-foot openings.

Pin cherry averaged at least 30 feet tall and nearly 3.0 inches dbh regardless of opening size or site.

SUMMARY AND DISCUSSION

A summary of the information on heights of the tallest saplings in 10-year-old clearcut circular openings ranging from 50 to 250 feet in diameter:

- Tallest sapling heights were not influenced by cardinal direction.
- For the good site, saplings in the center of 50- and 100-foot openings were significantly shorter than saplings in the 150-, 200-, and 250-foot openings. Also saplings in the 50-foot openings on the fair site were significantly shorter than those on the 150- and 250-foot openings.
- For the good site, saplings were significantly shorter along the border of 50-foot openings as compared to 100-, 150-, 200- or 250-foot openings. A similar trend was evident on the fair site, but the data were not significant. Within each size opening, saplings near the center of the openings were taller than those along the opening border with one exception—the 100-foot opening on the good site.

Individual sapling characteristics indicated that about 80 and 60 percent of these tallest saplings were of seedling origin on the good and fair sites respectively. Nearly all study stems were in the codominant and dominant crown classes, and about 90 percent of the commercial species (excluding pin cherry, American chestnut, and striped maple) were potential crop trees for sawlog production.

Sugar maple was the most numerous species on the good site, occurring as the tallest tree in about 50 percent of the sample plots on the 50-, 100-, and 150-foot openings. We suspect that these taller sugar maples were advance reproduction responding to the release. On the fair sites, red maple, sassafras, and unblighted American chestnut were the most abundant tall trees on 50- and 150-foot clearcut openings. For the larger openings on both sites, pin cherry, black locust, Fraser magnolia, sweet birch, and sassafras were the tallest; however, many of the pin cherry and American chestnut will soon die.

Comparing similar species in different size openings indicated that for sugar maple on the good site, the average height ranged from about 18 to 24 feet. For yellow-poplar and black cherry, height growth increased as opening size increased, averaging 17 feet or less in 100-foot openings to about 28 feet in the 250-foot openings.

Similarly, on the fair site red maple averaged 20 feet in 50-foot openings and 30 feet in 150- and 250-foot openings. Sassafras ranged from 15 feet in the 50-foot openings to 24 feet in the 150- and 250-foot openings.

Diameter (dbh) comparisons were similar in that, as the opening size increased, the dbh increased. Sugar maple was the exception. Sugar maple ranged in size from 1.4 to 2.0 inches dbh; yellow-poplar stems averaged 2.5 inches dbh for the 100-foot openings to 3.3 inches for the 250-foot openings, while black cherry averaged 2.6 inches dbh in 10 years for the 250-foot openings. Red maple averaged 1.6 inches dbh in the 50-foot openings to more than 3 inches dbh for the 250-foot openings. Sassafras ranged from 1.1 inches dbh in the 50-foot openings to about 2 inches dbh on the 150- and 250-foot openings.

Measurements of the tallest saplings in 25-foot-radius plots showed that openings of 150-foot diameter and larger (0.4 acre plus) had the taller dominant-codominant saplings when compared to the 50- and 100-foot diameter openings. Also, a greater variety of individual species was evident in the larger openings. The shading effect from trees along the opening borders, is less for saplings growing near the center of the larger openings compared to the smaller openings *(Sander and Clark 1971)*. This would strongly influence heights of the faster-growing, light-requiring saplings established near the center of the larger openings.

For good and fair oak sites, the expected height and dbh for the tallest dominant-codominant saplings in 10-year-old clearcut openings 150 feet in diameter or larger should be 25 to 30 feet tall and 2.5 to 3.0 inches dbh. This information provides silviculturists with an estimate of the potential growth of Appalachian hardwood saplings in a relatively free-to-grow crown position where the saplings have not received any cultural treatments.

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APPENDIX

Common and scientific names of species referred to in this study:

Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin	*Prunus pensylvanica* L.f.
Chestnut, American	*Castanea dentata* (Marsh.) Borkh.
Gum, black	*Nyssa sylvatica* Marsh.
Locust, black	*Robinia pseudoacacia* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pensylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Sourwood	*Oxydendrum arboreum* (L.) DC.
Yellow-poplar	*Liriodendron tulipifera* L.

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ABSTRACT

The squeeze between rising costs and product values is getting tighter for sawmill managers. So, they are taking a closer look at the efficiency of their sawmills by making a complete analysis of their milling situation. Such an analysis requires considerable time and expense.

To aid the manager with this task, the USDA Forest Service's Northeastern Forest Experiment Station and the Northeastern Area of State and Private Forestry have developed and field tested a computerized sawmill analysis technique called SOLVE II. Although the technique has been computerized, most sawmill managers do not have the manpower and computer facilities needed to collect and process the data. So, state utilization foresters in the Northeast and S&PF specialists are helping the sawmill managers to apply SOLVE II.

The flexibility of this technique allows it to be used for most hardwood mills and some softwood mills. Mill layout does not affect its use as long as the sawn products for each individual log can be followed through the mill. However, it is necessary that the mill: (1) processes logs with scaling diameters of at least 6 inches and no greater than 30 inches, (2) processes logs with lengths of at least 8 feet and no greater than 16 feet, (3) at least partially processes all logs through one piece of equipment that limits production, and (4) has the necessary operating cost information. Managers of sawmills that meet these requirements will find SOLVE II a useful tool in analyzing their milling situation.

SOLVE II

A TECHNIQUE TO IMPROVE EFFICIENCY AND SOLVE PROBLEMS IN HARDWOOD SAWMILLS

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FOREWORD

This is the first of a series of five papers about the SOLVE II technique for analyzing hardwood sawmills. It gives the reader a general idea of the SOLVE II technique and explains what it will do. The second paper will be a step-by-step manual for using the technique to analyze a sawmill. The third paper will document the SOLVE II computer program and the procedure used to process the data. The fourth paper will show how the SOLVE II outputs are used to analyze a sawmill. And, the fifth paper will show standards, developed from the SOLVE II analysis of many sawmills, that can be used to judge the efficiency of specific mill types.

INTRODUCTION

RECENTLY, HARDWOOD SAWMILL MANAGERS have experienced increased log prices, a scarcity of desirable species, poor markets—especially for low-grade lumber, and a sharp increase in operating costs. Thus they are acutely aware of the need for least-cost processing efficiency in their mills.

To improve the efficiency of his mill, the manager should set up a program to: (1) increase yields from each log, (2) reduce conversion costs, (3) expand daily production, (4) upgrade product quality, (5) convert mill residue to profitable products, and (6) reduce downtime.

To meet these objectives, the manager needs the answers to the following questions: How much can I afford to pay for my sawlogs? For the products I make, what are my break-even log sizes for the various log grades by species? Are my conversion costs too great for some logs? Is my overrun what it should be? Am I making too many chips? Are my yields of No. 1 Common and Better lumber what they should be? And, do I have excessive downtime? There are other questions that the manager should consider, but these are the major ones.

Obviously, good records can provide some of the information needed by sawmill managers. Experience and observation will also help. But a properly designed mill study with specific objectives is the best source of information.

Until now, mill studies were complex and costly. They usually hindered production, and it took many hours to process the data by hand. Also, when new equipment was added, log sizes were changed, or new products were produced, the difficulty was increased. To overcome these problems, the manager needs an analytical tool that will provide the information needed for sound decision-making with a minimum of cost and effort.

To provide mill managers with such a tool, the USDA Forest Service's Northeastern Forest Experiment Station and Northeastern Area of State and Private Forestry (NA-S&PF) have developed and field-tested a computerized sawmill analysis technique called SOLVE II. The technique was computerized to minimize the time-consuming mathematics necessary for processing the input data.

We realize that most sawmill managers would find it difficult to use the SOLVE II technique without some assistance. Depending on the size and layout of the mill, from 3 to 12 men are usually required to collect accurate data. Once the data are collected, they must be placed on cards and run through a computer (520K capacity) with the SOLVE II computer program. Mill managers usually do not have this extra manpower available, nor do many of them have access to the necessary computer facilities. So the state utilization foresters for most northeastern states and NA-S&PF are providing the necessary assistance to make SOLVE II usable for sawmill managers.

This paper contains a general discussion of the SOLVE II concept, including descriptions of the analysis technique, the necessary input data, the output results, and some possible uses of the analysis technique.

SOLVE II TECHNIQUE

SOLVE II is used for both economic and noneconomic sawmill analysis. For the economic analysis, it provides information on chip yields (in dollars), lumber yields (in dollars), and product-conversion costs. From this information, SOLVE II provides the mill manager with: (1) the maximum values he can pay for his sawlogs for a preselected profit margin, and (2) the break-even value he can pay for his logs with a zero profit. The simplified relationships used to produce these log values are:

1. Maximum log value = product value - conversion cost - profit.
2. Zero profit log values = product value - conversion cost.

For the noneconomic analysis, SOLVE II provides information for checking such things as lumber overrun, lumber grade yields, lumber-recovery factor (LRF), chip yields, and sawing times.

SOLVE II not only provides a variety of analytical information; but also its flexibility allows it to be used for most hardwood mills and some softwood mills. This flexibility is reflected in the fact that mill layout does not affect the use of the technique as long as the sawn products for each individual log can be followed through the mill. The technique can also be applied to a variety of products without difficulty. However, the mill must meet the following requirements:

1. Process logs with scaling diameters of at least 6 inches and no greater than 30 inches.
2. Process logs with lengths of at least 8 feet and no greater than 16 feet. Odd-length logs are acceptable.
3. At least partially process all logs through one piece of equipment, usually a headsaw, that limits production.
4. Have cost data that reflect the cost of operating the mill from log yard through sale of products.

Once it has been determined that a sawmill meets these requirements, the data are collected, punched on cards, and processed with the SOLVE II computer program.

A logical question at this point is how many logs must be included in the sample. Obviously, only five or six logs for a given log grade will not be enough. We have found that satisfactory results can usually be obtained with at least four logs in each size class sampled within a species and log grade. In other words, if your sample includes a 16-foot log with a 12-inch scaling diameter, you should have at least four logs in this size class. But the sample does not need to include four logs for each size class in the range of size classes normally processed at the mill. The following tabulation shows what might be a satisfactory number of logs for a sample of a given species and log grade:

Diameter class (inches)	*Log length class (feet)*				
	8	*10*	*12*	*14*	*16*
10	4	0	4	0	0
11	4	7	4	4	4
12	5	14	15	5	5
13	4	5	4	0	0
14	5	0	0	5	0
15	0	0	4	0	0

SOLVE II INPUTS

The input data are divided into two groups. The first consists of basic mill data. The second consists of the information related to each sawlog. Elements of both input groups are listed below to show the type of information needed to produce the SOLVE II outputs.

Basic mill data

1. Average yearly mill operating cost in dollars per minute.
2. Desired profit margin (percent of product sales).
3. Desired risk margin (percent of product sales).
4. Broker fee (percent of lumber sales) for selling lumber.
5. Cash discount (percent of lumber sales) to lumber buyers for prompt payment.
6. Lumber degrade factor for adjusting green lumber value to dry value due to shrinkage and degrade.
7. Average hours worked per day.
8. Average productive hours per day. (The difference between No. 7 and No. 8 is average downtime.)
9. Product prices.
10. Log rule used by the mill (International 1/4-inch, Doyle, Scribner Decimal C, or Vermont).

Sawlog data

1. Species name.
2. Log grade.
3. Small and large end diameters of each log (using Forest Service scaling procedure).
4. Log length (either nominal or actual).
5. Log defect volume in board feet (using Forest Service scaling procedure).
6. Sawing time for each log in minutes and hundredths of minutes.
7. Lumber yield by lumber grade and nominal thickness for each log.
8. Total green chip weight from a specific group of logs.

Not included in the above list of inputs are a number of codes and titles that are used by the computer to produce and identify the outputs. Also not included in the list are expected lumber yields by diameter class and lumber grades for different log grades and species. When these yields are included in the inputs, the SOLVE II program compares the actual yields with the expected yields.

SOLVE II OUTPUTS

SOLVE II outputs are divided into four groups: (1) input data listing, (2) data summary tables, (3) regression statistics, and (4) cost and value tables. Because of the large number of individual outputs, examples of all of them will not be shown in the following discussion. However, a sample of the outputs can be found in the appendix.

Input data listing

The basic mill data and sawlog data used as inputs to this analysis are also printed as outputs. This allows the sawmill analyst to check for errors that may have occurred when the data were transferred from the tally sheets to computer cards. Also, when this listing is kept with the other outputs for a particular mill, it provides a complete picture of the analysis.

Data summary tables

The data summary tables are used to organize the input data into a usable form. Some of the tables are printed only to provide a more complete picture of the data. Others are printed to allow comparisons of the analysis results with published or known results.

The types of summary tables are listed below. Tables 1 through 10 in this list show summaries by diameter class for each log grade. Tables 11 through 16 show summaries by diameter and length classes for each log grade.

1. Number of sample logs
2. Lumber tally yields
3. Cubic-foot log volumes
4. Gross log volumes for three different log rules (International 1/4-inch, Scribner Decimal C, and Doyle or Vermont).
5. Net log volumes for the three different log rules
6. Lumber-recovery factors
7. Lumber overrun for the three different log rules
8. Lumber grade yields
9. Actual versus expected lumber grade yields
10. Nominal lumber thickness yields
11. Log frequency distribution
12. Green chip yields in tons per thousand board feet (MBF) (lumber tally)
13. Curved sawing times per log
14. Curved sawing times per MBF (lumber tally)
15. Curved lumber tally yields per log
16. Curved lumber tally yields per MBF (International 1/4-inch, Scribner Decimal C, Doyle, or Vermont)

Several of the above types of tables are shown for three different log rules. These tables are always shown for the International 1/4-inch, Scribner Decimal C, and Doyle rules unless the mill being analyzed is using the Vermont rule. In that case, tables for the Doyle rule are replaced by tables for the Vermont rule.

Regression statistics

In processing the input data, the computer performs six regressions for each log grade within a species to provide equations for curved average value by diameter and length classes. Equations are developed on the following data:

1. Log sawing time per log.
2. Log sawing time per MBF (lumber tally).
3. Board-foot lumber yields per log.
4. Board-foot lumber yields per MBF (International 1/4-inch, Scribner Decimal C, Doyle, or Vermont).
5. Dollar lumber values per log.
6. Dollar lumber values per MBF (lumber tally).

For each regression, the SOLVE II output shows the regression statistics and the resulting equation. Along with this information, graphs are presented showing plots of the data and the resulting curved values. This information allows the sawmill analyst to assure that the curves fit the data satisfactorily. He may also use this information to check for insufficient or erroneous data.

Cost and value tables

This part of the SOLVE II output consists of 10 separate tables of dollar values by diameter and length class for each log grade. The tables show:

1. Curved lumber values in dollars per log.
2. Curved lumber values in dollars per MBF (lumber tally).
3. Chip values in dollars per log.
4. Chip values in dollars per MBF (lumber tally).
5. Total product values (chips plus lumber) in dollars per log, with deductions for broker fee and cash discount.
6. Total product values (chips plus lumber) in dollars per MBF (lumber tally), with deductions for broker fee and cash discount.
7. Product-conversion costs in dollars per log.
8. Product-conversion costs in dollars per MBF (lumber tally).
9. Maximum log values in dollars per MBF (log scale).
10. Zero profit log values in dollars per MBF (log scale).

The log scale used in tables listed as 9 and 10 is the log scale used by the sawmill. This can be either International 1/4-inch, Scribner Decimal C, Doyle, or Vermont. Table 9 (maximum log values in dollars per MBF log scale) shows what the mill operator can afford to pay for his delivered sawlogs for a desired profit and risk situation. Table 10 (Zero profit log values in dollars per MBF log scale) shows the prices that the mill operator can pay for his sawlogs and just break even. Thus, if he pays more for any of his logs than the values shown in this table, he will lose money on those logs.

SOLVE II USES

In development and testing, SOLVE II has already been used to answer management questions for a number of sawmills. For example, it was used in one Lake States mill to tell a manager whether he could afford to saw aspen logs, since his white pine resources were scarce. It was used in another Lake States mill to provide the mill manager with his break-even log sizes. These sizes were then used as a guide for his whole-tree chipping operation in the woods. In New England, the SOLVE concept was used to tell a mill manager whether he could afford to haul big white pine logs 200 miles. And it was used in a Middle Atlantic state to tell a mill manager how much he could afford to pay for his grade-1 logs to assure a steady supply of higher value logs. These are only a few of the questions that SOLVE II has answered for mill managers.

We will not attempt to discuss all of the possible uses of the SOLVE II outputs. Instead, we will look at how the outputs can be used to answer a few major questions for the sawmill manager. The questions that will be discussed are:

1. Is the efficiency of the mill satisfactory?
2. Are the yields by lumber grade satisfactory?
3. What can the mill manager afford to pay for his sawlogs for a given profit and risk situation?
4. What are the sawmills' break-even log sizes?

Is the efficiency of the mill satisfactory?

Two tables in the output that help answer this question are: (1) lumber-recovery factor (LRF) by log grade and diameter class, and (2) lumber overrun by log grade and diameter class for three log rules.

The table of lumber-recovery factors (LRF is calculated by dividing the board-foot lumber yield by the cubic-foot log volume) is one measure of the efficiency of a mill. The table not only shows these factors by diameter class for each log grade, but also shows average factors for each log grade and an average factor for all grades combined. When these factors are known for different mill types, the mill manager can compare the efficiency of his mill with that of other mills sawing similar logs and producing similar products.

Another measure of efficiency is the lumber overrun obtained by the sawmill. Tables of percent overrun by diameter class and log grade are shown for three log rules so the sawmill manager can check his overrun with published or known overruns even if they are shown for a log rule different from the one he is using. This allows the manager to compare the efficiency of his mill with that of mills in similar situations in different parts of the country.

If the mill manager finds that his lumber-recovery factors or overruns are lower than they should be, there are several things he can do.

First, he can check his chip yields. If they seem unusually high, he can check to make sure the head sawyer is not slabbing too heavily. He can also check trimming and edging practices. If these spot checks do not pinpoint the problem, it may be necessary to set up some small studies in specific areas of the sawmill. The important thing is that the mill manager's attention has been directed to a problem area.

Are the yields by lumber grade satisfactory?

To help answer this question, tables are printed that show actual yields in percent by lumber grade and diameter class for each log grade. If expected yields are known and entered as input data, the outputs also show a comparison of the mills' yields with the expected yields. This comparison is based only on the log diameter classes that are found in both the actual yields and the expected yields.

If the sawmill operator does not know the expected lumber yields for his log grades, he can find lumber yields for a number of species in Forest Service Research Paper FPL-63.[1] These yields are shown for the Forest Service log grades only. Of course, the study logs would then have to be graded according to FS standards. The Grade and Quality of Hardwood Timber Project (Work Unit 3102) of the Northeastern Forest Experiment Station at Delaware, Ohio, is in the process of upgrading these FPL-63 yields with new information for approximately 14 species. The revised yield tables should be available soon. Also, we are in the process of developing standards for different milling situations. Once these standards have been prepared, they will be available for use in the analysis.

If the manager enters expected yields as input data and finds that his lumber grade yields (for example, No. 1 Common and Better) for a given log grade are well below the expected yields, he should first try to explain this difference by checking the products he is producing. Special products can affect the yields in some lumber grades. If he cannot attribute the difference to special products, he should then check the practices used by his head sawyer, edgerman, and trimmerman. Finally, he might check his log-grading and lumber-inspection practices.

What can the mill manager afford to pay for his sawlogs for a given profit and risk situation?

To help answer this question, the output provides tables showing the maximum values in dollars per MBF log scale, by diameter and length classes for each log grade. Each of these tables also shows the average maximum price per MBF log scale that the mill operator could have paid for the logs used in the analysis. These maximum dollar values are what the manager can pay for his logs and still make the desired profit.

If the mill manager is paying more for his sawlogs than the values shown in the tables, he is not making his desired profit. To improve profitability, he must increase lumber recovery, reduce costs, upgrade products, or achieve some combination of these.

If he is paying less than the values shown in the tables, he can use the tables as guides for buying future logs. If supply has been a problem, he may want to pay more for his logs to attract a larger supply of logs. Or, to improve his supply of better logs, he may want to pay more for his better logs and less for poorer logs.

The tables of maximum sawlog values can also be used to show the effect that a change in mill operating cost or a change in product selling prices would have on what can be paid for sawlogs. As long as the products cut and the mill layout remain the same, the manager can change the price or the cost data and rerun the original data to get updated table values. This can be done every time there is a significant change in price or cost.

What are the mills' break-even log sizes?

To help answer this question, the output provides tables of zero-profit log values by diameter and length classes for each log grade. Any logs showing a negative value in these tables cost more to process than the value of the products obtained from them. These logs are usually found in the lower log grades, but may be found in higher grades of low-value species.

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[1] Vaughn, C. L., A. C. Wollin, K. A. McDonald, and E. H. Bulgrin. **Hardwood log grades for standard lumber.** USDA For. Serv. Res. Pap. FPL-63, 52 p., illus. U. S. For. Prod. Lab., Madison, Wis. 1966.

By subtracting his current log price from the dollar values found in the zero-profit table, the mill manager can find potential dollar profit or dollar loss for each size class of logs. A zero difference (table value same as log price) indicates that the logs in that size class are break-even logs. A positive difference indicates the potential profit for that log size. And a negative difference indicates the potential loss for that log size.

A sawmill manager usually must take the logs as they come. However, if the zero-profit table shows that he is getting too many logs below his break-even sizes, he may want to consider adding equipment that can process these logs at a lower cost. Or, he might investigate the market for products that will give a better return. Even if he cannot do anything about these logs, it is important that the sawmill manager know that they are not paying for themselves so that he can search for a solution to the problem.

CONCLUSION

The questions discussed above are of the type that can be answered with the SOLVE II sawmill analysis technique. For many questions, the output does not identify the specific problem, but it does indicate problem areas. In some cases, close observation during the data-collection phase of the analysis may help to pinpoint the problems. In other cases, it may be necessary to return to the mill for specific tests. Even though problems may not be pinpointed, it is important to note that SOLVE II allows the sawmill manager to take a good overall look at his operation with a minimum of effort.

To aid in the future use of SOLVE II, we plan to publish a paper showing standards that can be used to judge the efficiency of specific mill types. These standards will be developed from the SOLVE II analysis of many sawmills and will be shown for such things as LRF, overrun, lumber grade yield, conversion costs, chip yields, and downtime. Rough standards have already been developed from the sawmill information that was used to develop and test this analysis technique. These standards will be improved as more information becomes available.

SOLVE II is now being used by state foresters as part of their program to improve the efficiency of hardwood sawmills in eight northeastern states. Mill efficiency and profitability walk hand in hand. Tightening mill operations and eliminating poor practices will help increase yields, reduce costs, increase production, upgrade products, and reduce residues. Mill managers have come a long way toward meeting these objectives. However, SOLVE II can help them go even further, and make more efficient use of our renewable resources.

APPENDIX

The purpose of this Appendix is to show the different types of information that can be found in the SOLVE II printout. Only one example is shown for each type of information. For example, the regression analysis is shown only for sawing times per log. In a total printout, regression analyses are also shown for five other types of information. Some of the tables have been abridged to save space (this is shown by arrows) and the space between them has been reduced.

INPUT DATA

```
MILL......................ED'S MILL
DATE...................... 11 / 13 / 75
OPERATING COST / MINUTE..  1.23
CHIP PRICE / TON......... 10.50
DESIRED PROFIT MARGIN....    15
NECESSARY RISK MARGIN....     1
BROKER FEE...............     0
CASH DISCOUNT............     1
AVE. PROD. TIME / DAY....  7.33
AVE. HOURS WORK / DAY....  8.00
MILL TYPE CODE...........  5
```

```
                          LUMBER PRICES
                       SPECIES - HARD MAPLE

 THICK                                LUMBER GRADE
 -NESS       FAS   SEL    1C    2C    3C

  2/4          0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  3/4          0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  4/4        325.  305.  230.  150.  130.    0.    0.    0.    0.    0.    0.
  5/4          0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  6/4        350.  330.  260.  155.  135.    0.    0.    0.    0.    0.    0.
  7/4          0.    0.    0.    0.    0.    0.    0.    0.    0.    0.    0.
  8/4          0.    0.    0.    0.  118.    0.    0.    0.    0.    0.    0.
```

```
                              RAW LUMBER YIELD DATA

LOG  LOG   SMALL LARGE LOG  LOG         SPECIES         SAWING        SAWING
NO.  GRADE DIAM. DIAM. LGTH DEF.                         TIME          ORDER

       BOARD   LBR  SURF   LBR  SURF   LBR  SURF    LBR  SURF    LBR  SURF   LBR  SURF
       THICK   GRD  MEAS   GRD  MEAS   GRD  MEAS    GRD  MEAS    GRD  MEAS   GRD  MEAS/
234    3  17.   17.  10.0   20. HARD MAPLE             1.40          1
         4.     3    6.    4   23.     5   17.    0     0.     0    0.     0     0.
         6.     5   23.    0    0.     0    0.    0     0.     0    0.     0     0.
244    3  17.   19.  14.0   21. HARD MAPLE             2.30          2
         4.     2    8.    3    5.     4   22.    5    23.     0    0.     0     0.
         6.     2   14.    3   26.     4   16.    5     7.     0    0.     0     0.
205    2  16.   18.  14.0   20. HARD MAPLE             1.41          3
         4.     1    7.    2    7.     3   23.    0     0.     0    0.     0     0.
         6.     2   28.    3    9.     4   18.    0     0.     0    0.     0     0.
241    3  17.   21.  10.0   33. HARD MAPLE             1.50          4
         4.     1    5.    2    4.     3   20.    4     5.     5    5.     0     0.
         6.     3   24.    4    5.     0    0.    0     0.     0    0.     0     0.
167    2  17.   18.  10.0   24. HARD MAPLE             1.51          5
         4.     2   11.    4    7.     5   25.    0     0.     0    0.     0     0.
         6.     1   12.    3   18.     4    5.    0     0.     0    0.     0     0.
166    3  17.   17.  10.0   12. HARD MAPLE             1.30          6
         4.     3    7.    4    4.     5    5.    0     0.     0    0.     0     0.
         6.     1    7.    2    8.     3    9.    4    20.     5   14.     0     0.
```

↓ ↓ ↓

DATA SUMMARY TABLES

```
                              HARD MAPLE
 DIAM.                  NO OF LOGS BY LOG GRADE                          DIAM.
 CLASS        1            2           3           4           5          TOTL
--------------------------------------------------------------------------------
   10         0           11          10           0           0     |      21
   11         0           15          17           0           0     |      32
   12         0           15          16           0           0     |      31
   13         0           17          15           0           0     |      32
   14         0           17          15           0           0     |      32
   15         0           15          15           0           0     |      30
   16         0           16          15           0           0     |      31
   17         0           16          13           0           0     |      29
--------------------------------------------------------------------------------
GRADE                                                                |
  TOTL        0          122         116           0           0     |     238
```

```
                              HARD MAPLE
 DIAM.              BF LUMBER TALLY BY LOG GRADE                         DIAM.
 CLASS        1            2           3           4           5          TOTL
--------------------------------------------------------------------------------
   10         0          659         458           0           0     |    1117
   11         0          899        1181           0           0     |    2080
   12         0         1373        1233           0           0     |    2606
   13         0         1531        1452           0           0     |    2983
   14         0         1919        1671           0           0     |    3590
   15         0         1856        1721           0           0     |    3577
   16         0         2278        1995           0           0     |    4273
   17         0         2559        1910           0           0     |    4469
--------------------------------------------------------------------------------
GRADE                                                                |
  TOTL        0        13074       11621           0           0     |   24695
```

```
                              HARD MAPLE
 DIAM.    CUBIC FT. LOG VOLUME BY LOG GRADE                              DIAM.
 CLASS        1            2           3           4           5          TOTL
--------------------------------------------------------------------------------
   10       0.0       90.697      75.835         0.0         0.0     | 166.532
   11       0.0      150.726     171.571         0.0         0.0     | 322.297
   12       0.0      183.716     185.632         0.0         0.0     | 369.348
   13       0.0      228.277     203.775         0.0         0.0     | 432.052
   14       0.0      281.571     235.942         0.0         0.0     | 517.512
   15       0.0      272.293     260.704         0.0         0.0     | 532.997
   16       0.0      325.988     294.072         0.0         0.0     | 620.060
   17       0.0      369.111     273.720         0.0         0.0     | 642.831
--------------------------------------------------------------------------------
GRADE                                                                |
  TOTL      0.0     1902.379    1701.250         0.0         0.0     |3603.628
```

```
                              HARD MAPLE
 DIAM.             GRS LOG VOL DOYLE BY LOG GRADE                        DIAM.
 CLASS        1            2           3           4           5          TOTL
--------------------------------------------------------------------------------
   10         0          304         268           0           0     |     572
   11         0          591         689           0           0     |    1280
   12         0          780         832           0           0     |    1612
   13         0         1127         975           0           0     |    2102
   14         0         1371        1233           0           0     |    2604
   15         0         1455        1500           0           0     |    2955
   16         0         1872        1728           0           0     |    3600
   17         0         2200        1724           0           0     |    3924
--------------------------------------------------------------------------------
GRADE                                                                |
  TOTL        0         9700        8949           0           0     |   18649
```

HARD MAPLE

DIAM. CLASS	GRS LOG VOL SCRIB.C BY LOG GRADE 1	2	3	4	5	DIAM. TOTL
10	0	420	350	0	0	770
11	0	730	870	0	0	1600
12	0	970	1040	0	0	2010
13	0	1320	1140	0	0	2460
14	0	1570	1410	0	0	2980
15	0	1700	1750	0	0	3450
16	0	2080	1920	0	0	4000
17	0	2400	1890	0	0	4290
GRADE TOTL	0	11190	10370	0	0	21560

HARD MAPLE

DIAM. CLASS	GRS LOG VOL INT 1/4 BY LOG GRADE 1	2	3	4	5	DIAM. TOTL
10	0	515	450	0	0	965
11	0	920	1080	0	0	2000
12	0	1140	1220	0	0	2360
13	0	1580	1365	0	0	2945
14	0	1820	1635	0	0	3455
15	0	1860	1925	0	0	3785
16	0	2300	2120	0	0	4420
17	0	2640	2060	0	0	4700
GRADE TOTL	0	12775	11855	0	0	24630

HARD MAPLE

DIAM. CLASS	NET LOG VOL DOYLE BY LOG GRADE 1	2	3	4	5	DIAM. TOTL
10	0	304	268	0	0	572
11	0	578	689	0	0	1267
12	0	766	832	0	0	1598
13	0	1118	969	0	0	2087
14	0	1371	1220	0	0	2591
15	0	1418	1474	0	0	2892
16	0	1813	1728	0	0	3541
17	0	2159	1638	0	0	3797
GRADE TOTL	0	9527	8818	0	0	18345

HARD MAPLE

DIAM. CLASS	NET LOG VOL SCRIB.C BY LOG GRADE 1	2	3	4	5	DIAM. TOTL
10	0	420	350	0	0	770
11	0	717	870	0	0	1587
12	0	956	1040	0	0	1996
13	0	1311	1134	0	0	2445
14	0	1570	1397	0	0	2967
15	0	1663	1724	0	0	3387
16	0	2021	1920	0	0	3941
17	0	2359	1804	0	0	4163
GRADE TOTL	0	11017	10239	0	0	21256

```
                                HARD MAPLE
  DIAM.      NET LOG VOL INT 1/4 BY LOG GRADE                          DIAM.
  CLASS      1           2          3          4          5            TOTL
--------------------------------------------------------------------------
   10        0          515        450         0          0       |     965
   11        0          907       1080         0          0       |    1987
   12        0         1126       1220         0          0       |    2346
   13        0         1571       1359         0          0       |    2930
   14        0         1820       1622         0          0       |    3442
   15        0         1823       1899         0          0       |    3722
   16        0         2241       2120         0          0       |    4361
   17        0         2599       1974         0          0       |    4573
--------------------------------------------------------------------------
GRADE                                                             |
 TOTL        0        12602      11724         0          0       |   24326
```

```
                                HARD MAPLE
  DIAM.     LUMBER RECOV. FACT. BY LOG GRADE                           DIAM.
  CLASS     1           2          3          4          5             AVE
--------------------------------------------------------------------------
   10     0.0         7.266      6.039      0.0        0.0       |   6.707
   11     0.0         5.964      6.883      0.0        0.0       |   6.454
   12     0.0         7.473      6.642      0.0        0.0       |   7.056
   13     0.0         6.707      7.125      0.0        0.0       |   6.904
   14     0.0         6.815      7.082      0.0        0.0       |   6.937
   15     0.0         6.816      6.601      0.0        0.0       |   6.711
   16     0.0         6.988      6.784      0.0        0.0       |   6.891
   17     0.0         6.933      6.978      0.0        0.0       |   6.952
--------------------------------------------------------------------------
GRADE                                                            |
 AVE      0.0         6.872      6.831      0.0        0.0       |   6.853
```

```
                                HARD MAPLE
  DIAM.             OVER RUN DOYLE BY LOG GRADE                        DIAM.
  CLASS      1           2          3          4          5            AVE
--------------------------------------------------------------------------
   10       0.0        116.8       70.9       0.0        0.0      |    95.3
   11       0.0         55.5       71.4       0.0        0.0      |    64.2
   12       0.0         79.2       48.2       0.0        0.0      |    63.1
   13       0.0         36.9       49.8       0.0        0.0      |    42.9
   14       0.0         40.0       37.0       0.0        0.0      |    38.6
   15       0.0         30.9       16.8       0.0        0.0      |    23.7
   16       0.0         25.6       15.5       0.0        0.0      |    20.7
   17       0.0         18.5       16.6       0.0        0.0      |    17.7
--------------------------------------------------------------------------
GRADE                                                             |
 AVE        0.0         37.2       31.8       0.0        0.0      |    34.6
```

```
                                HARD MAPLE
  DIAM.           OVER RUN SCRIB.C BY LOG GRADE                        DIAM.
  CLASS      1           2          3          4          5            AVE
--------------------------------------------------------------------------
   10       0.0         56.9       30.9       0.0        0.0      |    45.1
   11       0.0         25.4       35.7       0.0        0.0      |    31.1
   12       0.0         43.6       18.6       0.0        0.0      |    30.6
   13       0.0         16.8       28.0       0.0        0.0      |    22.0
   14       0.0         22.2       19.6       0.0        0.0      |    21.0
   15       0.0         11.6       -0.2       0.0        0.0      |     5.6
   16       0.0         12.7        3.9       0.0        0.0      |     8.4
   17       0.0          8.5        5.9       0.0        0.0      |     7.4
--------------------------------------------------------------------------
GRADE                                                             |
 AVE        0.0         18.7       13.5       0.0        0.0      |    16.2
```

```
                              HARD MAPLE
 DIAM.       OVER RUN INT 1/4 BY LOG GRADE                          DIAM.
 CLASS     1          2          3          4          5           AVE
------------------------------------------------------------------------
   10     0.0       28.0        1.8        0.0        0.0     |    15.8
   11     0.0       -0.9        9.4        0.0        0.0     |     4.7
   12     0.0       21.9        1.1        0.0        0.0     |    11.1
   13     0.0       -2.5        6.8        0.0        0.0     |     1.8
   14     0.0        5.4        3.0        0.0        0.0     |     4.3
   15     0.0        1.8       -9.4        0.0        0.0     |    -3.9
   16     0.0        1.7       -5.9        0.0        0.0     |    -2.0
   17     0.0       -1.5       -3.2        0.0        0.0     |    -2.3
------------------------------------------------------------------------
GRADE                                                         |
 AVE      0.0        3.7       -0.9        0.0        0.0     |     1.5
```

From this point on, the output is shown for each log grade found in the input data.

```
                               HARD MAPLE


          LUMBER GRADE YIELD FOR LOG GRADE  2 IN PERCENT

DIAM.  NO.    LUMBER                    LUMBER GRADES
CLASS  LOGS   TALLY       FAS    SEL    1C     2C     3C
-------------------------------------------------------------------------
   10  11.      659.  |   2.1   10.3   17.3   36.6   33.7   0.0    0.0    0.0
   11  15.      899.  |   3.8    5.8   15.1   29.9   45.4   0.0    0.0    0.0
   12  15.     1373.  |   2.2    8.7   22.7   26.7   39.8   0.0    0.0    0.0
   13  17.     1531.  |   2.5   14.2   20.6   23.8   38.9   0.0    0.0    0.0
   14  17.     1919.  |   6.8   24.3   24.8   20.2   24.0   0.0    0.0    0.0
   15  15.     1856.  |   6.4   18.0   26.8   17.0   31.7   0.0    0.0    0.0
   16  16.     2278.  |   7.0   22.9   25.2   19.2   25.7   0.0    0.0    0.0
   17  16.     2559.  |  17.2   20.8   24.2   16.2   21.6   0.0    0.0    0.0
-------------------------------------------------------------------------
 AVE. 122.    13074.  |   7.4   17.7   23.3   21.4   30.3   0.0    0.0    0.0



                          ACT. VS. EXP. LUMBER GRADE YIELDS IN PERCENT
                                          LOG GRADE 2

            | DIAM. | NO.  |                 LUMBER GRADE
            | RANGE | LOGS |   FAS    SEL    1C     2C     3C
----------------------------------------------------------------------
 ACT. AVE.  | 10- 17| 122  |   7.4   17.7   23.3   21.4   30.3    0.0    0.0
----------------------------------------------------------------------
            | DIAM. | NO.  |                 LUMBER GRADE
            | RANGE | LOGS |   FAS    SEL    1C     2C     3C
----------------------------------------------------------------------
 EXP. AVE.  | 10- 17|1108  |   5.2    8.0   27.6   24.1   35.0    0.0    0.0
----------------------------------------------------------------------
```

```
          LUMBER THICKNESS YIELD FOR LOG GRADE  2 IN PERCENT


DIAM.  THICK                         LUMBER GRADES
CLASS  -NESS   FAS     SEL     1C     2C     3C                 AVE.
----------------------------------------------------------------
 10          |
           2 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           3 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           4 |   0.0    26.5    61.4   57.7   57.2    0.0       53.7
           5 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           6 | 100.0    73.5    38.6   42.3   42.8    0.0       46.3
           7 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           8 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
 11          |
           2 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           3 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           4 |  14.7    32.7    39.7   78.8   62.0    0.0       60.2
```

```
           6 |  75.6    81.0    73.4   41.6   66.8    0.0       67.5
           7 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           8 |   0.0     0.0     0.0    0.0    1.0    0.0        0.3
 17          |
           2 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           3 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           4 |  11.6    26.1    39.8   57.2   48.1    0.0       36.7
           5 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           6 |  88.4    73.9    60.2   42.8   51.9    0.0       63.3
           7 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           8 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
----------------------------------------------------------------
AVE.         |
           2 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           3 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           4 |  16.6    24.3    38.2   66.3   45.1    0.0       42.2
           5 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           6 |  83.4    75.7    61.8   33.7   52.1    0.0       56.9
           7 |   0.0     0.0     0.0    0.0    0.0    0.0        0.0
           8 |   0.0     0.0     0.0    0.0    2.8    0.0        0.9
```

```
                         HARD MAPLE
              LOG FREQUENCY DISTRIBUTION (PERCENT)
                 BY LOG LENGTH AND DIAMETER
                      LOG GRADE -  2


LOG                          LOG LENGTH
DIAM.     6       8      10      12      14      16      18        AVE.
------------------------------------------------------------------------
  10 |   0.0     0.0    3.28    3.28    0.0     2.46    0.0   |    9.02
  11 |   0.0     0.0    3.28    3.28    3.28    2.46    0.0   |   12.30
  12 |   0.0     0.0    3.28    3.28    2.46    3.28    0.0   |   12.30
  13 |   0.0     0.0    3.28    3.28    4.10    3.28    0.0   |   13.93
  14 |   0.0     0.0    3.28    4.10    3.28    3.28    0.0   |   13.93
  15 |   0.0     0.0    3.28    3.28    3.28    2.46    0.0   |   12.30
  16 |   0.0     0.0    3.28    3.28    3.28    3.28    0.0   |   13.11
  17 |   0.0     0.0    3.28    3.28    3.28    3.28    0.0   |   13.11
------------------------------------------------------------------------
AVE. |   0.0     0.0   26.23   27.05   22.95   23.77    0.0   |
                    HARD MAPLE
         CHIP YIELD PER MBF (LUMBER TALLY)
            BY LOG LENGTH AND DIAMETER
                 LOG GRADE -  2

LOG                  LOG LENGTH
DIAM.       8       10      12      14      16
----------------------------------------------
  10 |     0.0     2.03    1.77    1.61    1.49
  11 |     0.0     1.77    1.58    1.45    1.35
  12 |     0.0     1.59    1.44    1.33    1.26
  13 |     0.0     1.46    1.33    1.25    1.18
  14 |     0.0     1.36    1.25    1.18    1.13
  15 |     0.0     1.28    1.19    1.13    1.08
  16 |     0.0     1.22    1.14    1.09    1.05
  17 |     0.0     1.17    1.10    1.05    1.02
----------------------------------------------
```

The following regression information and graphs are also shown for five other sets of information:

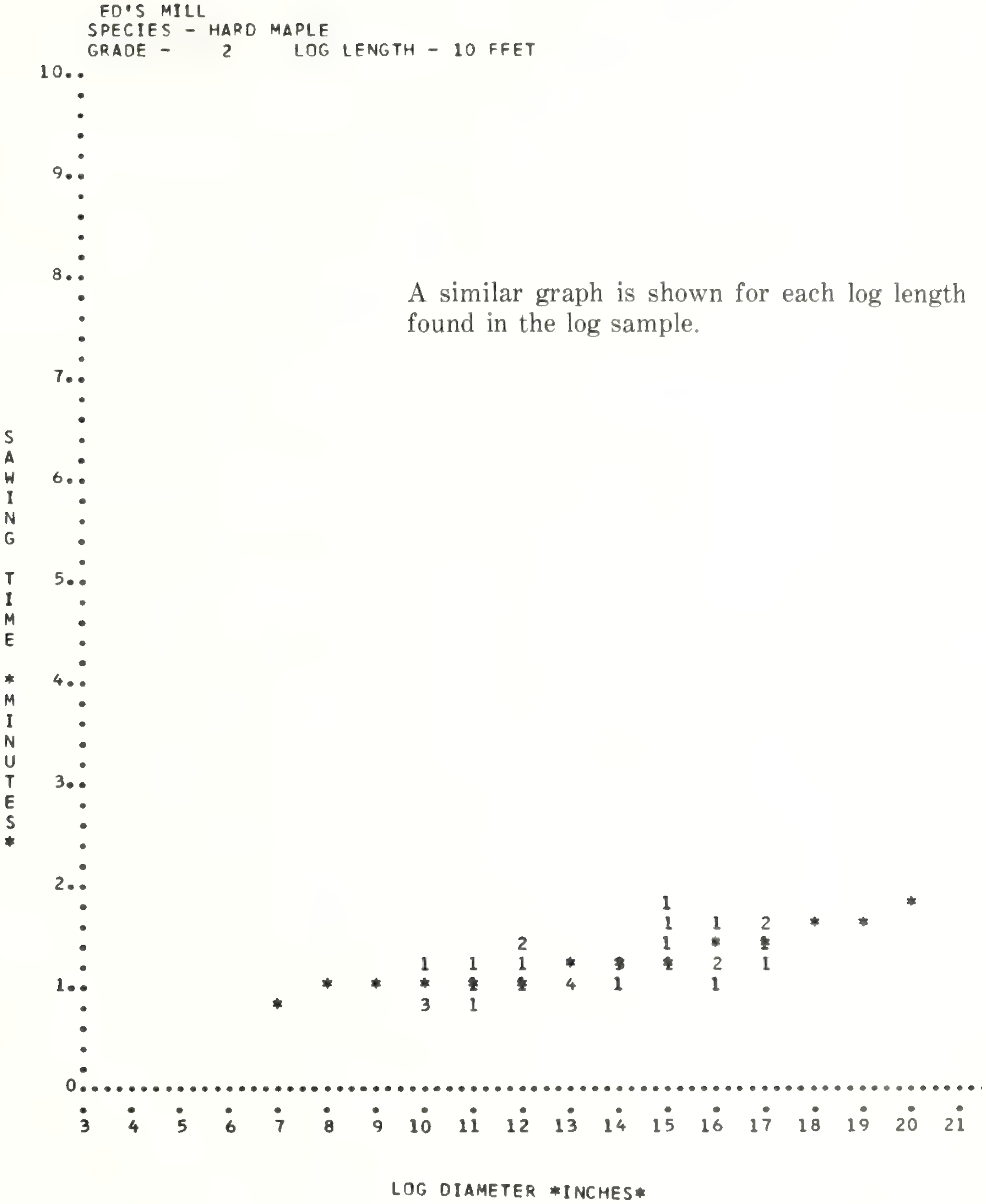
Sawing time / M bm
Lumber yield / log
Lumber yield / M bm
Dollar yield / log
Dollar yield / M bm (tally)

```
          ED'S MILL

          SPECIES - HARD MAPLE

                 LOG GRADE -    2

           SAWING TIME / LOG

                 EQUATION NO.  1

LEAST SQUARES SOLUTION -- Y=B0+(B1*X1)+(B2*X2)

                       Y = SAWING TIME / LOG (MINUTES)
                       X1 = LOG DIAMETER (INCHES)
                       X2 = X1 SQUARED X LOG LENGTH (FEET)

               ANALYSIS OF VARIANCE

 SOURCE        DF          SS              MS              F

 CONST.         1       219.8604        219.8604       2867.4485
   X1           1         4.5804          4.5804         59.7383
   X2           1         2.4505          2.4505         31.9596
  RES.        115         8.8176          0.0767
 TOTAL        118       235.7089

               CORRELATION COEFFICIENTS

         CORRELATION COEFFICIENT (X1,Y) = 0.53760
         CORRELATION COEFFICIENT (X2,Y) = 0.66260
         CORRELATION COEFFICIENT (X1,X2)= 0.86301
         MULT. CORRELATION COEFF.(  R  ) = 0.66606
         COEFF. OF DETERMINATION (R**2) = 0.44363

               REGRESSION COEFFICIENTS

                                 STANDARD ERROR

          B0 =        0.87719
          B1 =       -0.02252        0.02312
          B2 =        0.00032        0.00006

          STANDARD ERROR OF ESTIMATE =      0.27690


          EQUATION NO.  1

             Y =        0.87719 + (      -0.02252 * X1 ) + (          0.00032 * X2 )
```

```
                    ED'S MILL

                    SPECIES - HARD MAPLE

                            LOG GRADE -     2

                     SAWING TIME / LOG

                            EQUATION NO.  1


LEAST SQUARES SOLUTION -- Y=B0+(B1*X1)+(B2*X2)

                                 Y = SAWING TIME / LOG (MINUTES)
                                 X1 = LOG DIAMETER (INCHES)
                                 X2 = X1 SQUARED X LOG LENGTH (FEET)


                      OBSERVED AND PREDICTED VALUES


OBS.  LOG    LOG    LOG      OBSERVED       PREDICTED      RESIDUALS
NO.   NO.    DIAM.  LGTH        Y               Y


  1   205    16.    14.      1.41000        1.68067        0.27067
  2   167    17.    10.      1.51000        1.43278       -0.07722
  3   233    17.    10.      1.47000        1.43278       -0.03722
  4   228    16.    14.      1.55000        1.68067        0.13067
  5   237    17.    14.      1.78000        1.80818        0.02818
  6   139    17.    12.      2.01000        1.62048       -0.38952
  7   243    11.    16.      2.27000        1.25812       -1.01188
  8   240    10.    16.      1.24000        1.17154       -0.06846
  9   211    17.    10.      1.68000        1.43278       -0.24722
 10   194    10.    12.      0.97000        1.04164        0.07164




102    57    15.    14.      2.15000        1.56226       -0.58774
103    87    13.    14.      1.84000        1.35271       -0.48729
104    15    16.    10.      1.62000        1.34814       -0.27186
105    42    12.    16.      1.58000        1.35510       -0.22490
106    82    11.    12.      1.04000        1.10095        0.06095
107   137    11.    12.      0.94000        1.10095        0.16095
108   201    10.    12.      0.74000        1.04164        0.30164
109   152    12.    12.      1.03000        1.16806        0.13806
110    41    14.    12.      1.16000        1.32564        0.16564
111    28    16.    12.      1.38000        1.51441        0.13441
112   125    15.    16.      1.77000        1.70839       -0.06161
113    73    15.    12.      1.30000        1.41613        0.11613
114    75    13.    14.      1.27000        1.35271        0.08271
115   191    12.    14.      1.50000        1.26158       -0.23842
116    74    13.    14.      1.71000        1.35271       -0.35729
117    38    14.    12.      1.31000        1.32564        0.01565
118    32    15.    16.      1.54000        1.70839        0.16839
                 RESIDUAL CHECK FOR OUTLYING DATA

      UPPER LIMIT (+4 STAND. DEV.) =       1.09343

      LOWER LIMIT (-4 STAND. DEV.) =      -1.09343


                      OUTLYING RESIDUALS

      OBSERVATION                        RESIDUAL

         NONE                              NONE
```

Curved average values

Difference between observed and predicted values



A similar graph is shown for each log length found in the log sample.

```
        ED'S MILL

         CURVED LUMBER TALLY
           (VOLUME / LOG)

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*                LENGTH
    *    8      10      12      14      16
****************************************
    * -------- VOLUMES PER LOG --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -      46      54      63      71
 11 *   - -      54      65      75      85
 12 *   - -      64      76      88     101
 13 *   - -      74      88     103     117
 14 *   - -      85     102     118     135
 15 *   - -      97     116     135     155
 16 *   - -     110     132     153     175
 17 *   - -     123     148     173     197
 18 *   - -     - -     - -     - -     - -

****************************************

        107 = AVE. / LOG

****************************************
```

```
        ED'S MILL

          CURVED LUMBER YIELD
          (VOLUMES / MBF-(SCRI) )

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

*********************************************
DIAM*                  LENGTH
    *     8        10        12        14        16
*********************************************
    * ----------- VOLUMES PER MBF ----------
    *
  6 *    - -       - -       - -       - -       - -
  7 *    - -       - -       - -       - -       - -
  8 *    - -       - -       - -       - -       - -
  9 *    - -       - -       - -       - -       - -
 10 *    - -      1535      1505      1484      1469
 11 *    - -      1430      1405      1388      1375
 12 *    - -      1344      1324      1309      1298
 13 *    - -      1274      1256      1244      1234
 14 *    - -      1214      1199      1189      1180
 15 *    - -      1164      1151      1141      1134
 16 *    - -      1120      1109      1100      1094
 17 *    - -      1082      1072      1065      1059
 18 *    - -       - -       - -       - -       - -

*********************************************

        1185 = AVE. / MBF-(SCRI )

*********************************************
```

```
        ED'S MILL

         CURVED LUMBER VALUE
           (DOLLARS / LOG)

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*                LENGTH
    *    8      10      12      14      16
****************************************
    * -------- DOLLARS PER LOG --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -     5.99    8.16   10.34   12.52
 11 *   - -     8.49   11.12   13.75   16.39
 12 *   - -    11.20   14.34   17.47   20.61
 13 *   - -    14.14   17.82   21.50   25.18
 14 *   - -    17.29   21.56   25.82   30.09
 15 *   - -    20.66   25.56   30.46   35.36
 16 *   - -    24.25   29.82   35.39   40.97
 17 *   - -    28.05   34.35   40.64   46.93
 18 *   - -     - -     - -     - -     - -

****************************************

     22.83 = AVE. VALUE (DOLLARS) / LOG

****************************************
```

```
        ED'S MILL

         CURVED LUMBER VALUE
           (DOLLARS / MBF-LMBR TALLY)

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*                LENGTH
    *    8      10      12      14      16
****************************************
    * -------- DOLLARS PER MBF --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -   155.39  162.96  168.36  172.42
 11 *   - -   172.28  178.53  183.00  186.35
 12 *   - -   185.78  191.03  194.79  197.60
 13 *   - -   196.80  201.27  204.47  206.87
 14 *   - -   205.94  209.80  212.56  214.63
 15 *   - -   213.65  217.01  219.41  221.21
 16 *   - -   220.22  223.17  225.29  226.87
 17 *   - -   225.89  228.51  230.38  231.78
 18 *   - -     - -     - -     - -     - -

****************************************

210.68 = AVE. (DOLLARS) / MBF-LMBR TALLY

****************************************
```

```
        ED'S MILL

        CHIP VALUES
         ( DOLLARS PER LOG )

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*              LENGTH
    *     8      10      12      14      16
****************************************
    * -------- DOLLARS PER LOG --------
    *
  6 *    - -     - -     - -     - -     - -
  7 *    - -     - -     - -     - -     - -
  8 *    - -     - -     - -     - -     - -
  9 *    - -     - -     - -     - -     - -
 10 *    - -    0.97    1.01    1.06    1.11
 11 *    - -    1.01    1.07    1.14    1.21
 12 *    - -    1.06    1.15    1.24    1.33
 13 *    - -    1.13    1.24    1.35    1.46
 14 *    - -    1.21    1.34    1.47    1.60
 15 *    - -    1.30    1.45    1.60    1.76
 16 *    - -    1.40    1.57    1.75    1.92
 17 *    - -    1.51    1.71    1.91    2.11
 18 *    - -     - -     - -     - -     - -

****************************************

        1.39 = AVE. / LOG

****************************************
```

```
        ED'S MILL

        CHIP VALUES
           ( DOLLARS PER MBF-LMBR TALLY )

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*              LENGTH
    *     8      10      12      14      16
****************************************
    * -------- DOLLARS PER MBF --------
    *
  6 *    - -     - -     - -     - -     - -
  7 *    - -     - -     - -     - -     - -
  8 *    - -     - -     - -     - -     - -
  9 *    - -     - -     - -     - -     - -
 10 *    - -   21.26   18.62   16.86   15.62
 11 *    ---   18.61   16.57   15.21   14.23
 12 *    - -   16.72   15.10   14.00   13.21
 13 *    - -   15.33   14.00   13.09   12.43
 14 *    - -   14.27   13.16   12.39   11.84
 15 *    - -   13.44   12.49   11.84   11.36
 16 *    - -   12.78   11.96   11.39   10.98
 17 *    - -   12.24   11.53   11.03   10.67
 18 *    - -     - -     - -     - -     - -

****************************************

     12.98 = AVE. / MBF-LMBR TALLY

****************************************
```

```
        ED'S MILL

        PRODUCT VALUE
         ( DOLLARS PER LOG )

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*              LENGTH
    *     8      10      12      14      16
****************************************
    * -------- DOLLARS PER LOG --------
    *
  6 *    - -     - -     - -     - -     - -
  7 *    - -     - -     - -     - -     - -
  8 *    - -     - -     - -     - -     - -
  9 *    - -     - -     - -     - -     - -
 10 *    - -    6.90    9.09   11.30   13.51
 11 *    - -    9.41   12.08   14.76   17.44
 12 *    - -   12.16   15.34   18.53   21.73
 13 *    - -   15.13   18.88   22.63   26.38
 14 *    - -   18.33   22.68   27.03   31.39
 15 *    - -   21.76   26.75   31.76   36.76
 16 *    - -   25.41   31.10   36.79   42.48
 17 *    ---   29.28   35.71   42.14   48.56
 18 *    - -     - -     - -     - -     - -

****************************************

       23.99 = AVE. / LOG

****************************************
```

```
        ED'S MILL

        PRODUCT VALUE
           ( DOLLARS PER MBF-LMBR TALLY )

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

****************************************
DIAM*              LENGTH
    *     8      10      12      14      16
****************************************
    * -------- DOLLARS PER MBF --------
    *
  6 *    - -     - -     - -     - -     - -
  7 *    - -     - -     - -     - -     - -
  8 *    - -     - -     - -     - -     - -
  9 *    - -     - -     - -     - -     - -
 10 *    - -  175.10  179.94  183.54  186.31
 11 *    - -  189.17  193.32  196.38  198.71
 12 *    - -  200.65  204.23  206.84  208.83
 13 *    - -  210.16  213.26  215.52  217.24
 14 *    - -  218.15  220.86  222.83  224.32
 15 *    - -  224.95  227.33  229.06  230.36
 16 *    - -  230.79  232.90  234.43  235.58
 17 *    - -  235.87  237.75  239.10  240.13
 18 *    - -     - -     - -     - -     - -

****************************************

    221.56 = AVE. / MBF-LMBR TALLY

****************************************
```

```
         ED'S MILL

         SAWING TIMES
          ( MINUTES PER LOG )

         HARD MAPLE

         GRADE  2

         DATE  11/ 13/ 75

*****************************************
DIAM*              LENGTH
    *    8      10      12      14      16
*****************************************
    * -------- MINUTES PER LOG --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -    0.98    1.04    1.11    1.17
 11 *   - -    1.02    1.10    1.18    1.26
 12 *   - -    1.07    1.17    1.26    1.36
 13 *   - -    1.13    1.24    1.35    1.46
 14 *   - -    1.20    1.33    1.45    1.58
 15 *   - -    1.27    1.42    1.56    1.71
 16 *   - -    1.35    1.51    1.68    1.85
 17 *   - -    1.43    1.62    1.81    2.00
 18 *   - -     - -     - -     - -     - -

*****************************************

         1.37 = AVE. / LOG

*****************************************
```

```
         ED'S MILL

         SAWING TIMES
            ( MINUTES PER MBF-LMBR TALLY )

         HARD MAPLE

         GRADE  2

         DATE  11/ 13/ 75

*****************************************
DIAM*              LENGTH
    *    8      10      12      14      16
*****************************************
    * -------- MINUTES PER MBF --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -   19.44   18.06   17.08   16.34
 11 *   - -   17.58   16.44   15.62   15.01
 12 *   - -   16.12   15.17   14.48   13.97
 13 *   - -   14.97   14.16   13.57   13.14
 14 *   - -   14.04   13.33   12.83   12.45
 15 *   - -   13.27   12.65   12.22   11.89
 16 *   - -   12.62   12.09   11.70   11.41
 17 *   - -   12.08   11.60   11.26   11.01
 18 *   - -     - -     - -     - -     - -

*****************************************

     13.18 = AVE. / MBF-LMBR TALLY

*****************************************
```

```
         ED'S MILL

         CONVERSION COST
          ( DOLLARS PER LOG )

         HARD MAPLE

         GRADE  2

         DATE  11/ 13/ 75

*****************************************
DIAM*              LENGTH
    *    8      10      12      14      16
*****************************************
    * -------- DOLLARS PER LOG --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -    1.31    1.40    1.49    1.57
 11 *   - -    1.37    1.48    1.58    1.69
 12 *   - -    1.44    1.57    1.69    1.82
 13 *   - -    1.52    1.67    1.82    1.96
 14 *   - -    1.61    1.78    1.95    2.12
 15 *   - -    1.70    1.90    2.10    2.29
 16 *   - -    1.81    2.03    2.26    2.48
 17 *   - -    1.92    2.18    2.43    2.68
 18 *   - -     - -     - -     - -     - -

*****************************************

         1.84 = AVE. / LOG

*****************************************
```

```
         ED'S MILL

         CONVERSION COST
            ( DOLLARS PER MBF-LMBR TALLY )

         HARD MAPLE

         GRADE  2

         DATE  11/ 13/ 75

*****************************************
DIAM*              LENGTH
    *    8      10      12      14      16
*****************************************
    * -------- DOLLARS PER MBF --------
    *
  6 *   - -     - -     - -     - -     - -
  7 *   - -     - -     - -     - -     - -
  8 *   - -     - -     - -     - -     - -
  9 *   - -     - -     - -     - -     - -
 10 *   - -   26.10   24.25   22.93   21.94
 11 *   - -   23.59   22.07   20.97   20.15
 12 *   - -   21.65   20.36   19.44   18.75
 13 *   - -   20.10   19.00   18.22   17.63
 14 *   - -   18.84   17.90   17.22   16.72
 15 *   - -   17.81   16.99   16.40   15.96
 16 *   - -   16.95   16.22   15.71   15.32
 17 *   - -   16.22   15.58   15.12   14.78
 18 *   - -     - -     - -     - -     - -

*****************************************

     17.69 = AVE. / MBF-LMBR TALLY

*****************************************
```

```
        ED'S MILL

        MAXIMUM LOG VALUE
         ( DOLLARS PER MBF-( SCRI ))

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

*****************************************
DIAM*            LENGTH
    *    8      10      12      14      16
*****************************************
    * -------- DOLLARS PER MBF --------
    *
  6 *    - -     - -     - -     - -     - -
  7 *    - -     - -     - -     - -     - -
  8 *    - -     - -     - -     - -     - -
  9 *    - -     - -     - -     - -     - -
 10 *    - -  185.70  191.05  194.83  197.62
 11 *    - -  193.46  197.21  199.85  201.80
 12 *    - -  197.49  200.16  202.03  203.40
 13 *    - -  199.26  201.18  202.52  203.50
 14 *    - -  199.64  201.03  201.99  202.70
 15 *    - -  199.17  200.17  200.87  201.38
 16 *    - -  198.16  198.89  199.39  199.75
 17 *    - -  196.84  197.36  197.72  197.98
 18 *    - -     - -     - -     - -     - -

*****************************************

      199.52 = AVE. / MBF-(SCRI )

*****************************************
```

```
        ED'S MILL

      '0' PROFIT LOG VALUE
       ( DOLLARS PER MBF-( SCRI ))

        HARD MAPLE

        GRADE  2

        DATE  11/ 13/ 75

*****************************************
DIAM*            LENGTH
    *    8      10      12      14      16
*****************************************
    * -------- DOLLARS PER MBF --------
    *
  6 *    - -     - -     - -     - -     - -
  7 *    - -     - -     - -     - -     - -
  8 *    - -     - -     - -     - -     - -
  9 *    - -     - -     - -     - -     - -
 10 *    - -  228.71  234.39  238.42  241.40
 11 *    - -  236.73  240.69  243.46  245.51
 12 *    - -  240.65  243.42  245.36  246.79
 13 *    - -  242.09  244.05  245.41  246.41
 14 *    - -  242.03  243.41  244.37  245.07
 15 *    - -  241.05  242.02  242.69  243.18
 16 *    - -  239.52  240.20  240.66  241.00
 17 *    - -  237.67  238.13  238.45  238.67
 18 *    - -     - -     - -     - -     - -

*****************************************

      241.53 = AVE. / MBF-(SCRI )

*****************************************
```

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Adams, Edward L., and Daniel E. Dunmire.
1977. **SOLVE II: A technique to improve efficiency and solve problems in hardwood sawmills.**
Northeast. For. Exp. Stn. Upper Darby, Pa.
19 p. (U.S. Dep. Agric. For. Serv. Res. Pap. NE-382)

A general description of a computerized technique for analyzing hardwood sawmills. Included are discussions of the input data, the resulting analytical information, and examples of how this information can be used by a mill manager. The technique gives themanager an economic and noneconomic analysis of his sawmill's operation.

Keywords: sawmill operation, sawmill recovery studies, forest product prices, computer program

832.12

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Keywords: sawmill operation, sawmill recovery studies, forest product prices, computer program

832.12

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SEEDLING-SIZE FUMIGATION CHAMBERS

by **Keith F. Jensen and Frederick W. Bender**

FOREST SERVICE RESEARCH PAPER NE-383
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082

The Authors

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MANUSCRIPT RECEIVED FOR PUBLICATION 19 JANUARY 1977.

ABSTRACT

The design of fumigation chambers is described. Each chamber has individual temperature, humidity, light, and pollutant control. Temperature is variable from 15 to 35°C and controlled within ±1°C. Humidity is variable from 25 to 95 percent and controlled within ±3 percent. Seedlings have been successfully grown in these chambers for up to 3 months.

SINCE THE DISCOVERY that air pollution is a stress factor, many plants have been fumigated within enclosures of various designs, ranging from large outdoor chambers or greenhouses to small leaf chambers (Adams 1961; Berry 1970; Heagle, Body, and Pounds 1972; Heagle, Body, and Heck 1973; Heck, Dunning, and Johnson 1968; Hill 1967, Mandl and others 1973; Wood and others 1973). Each of the chambers was designed to meet a specific need that depended on the objectives of the researcher using it.

For our research we required a system of chambers both for fumigating forest tree seedlings for long periods of time at low concentrations and for fumigating large seedlings for short periods of time. The chambers needed to be environmentally controlled and equipped to regulate the concentrations of more than one pollutant.

The chambers described here meet these requirements and control temperature within ±1°C and relative humidity within 3 percent over a wide range of temperature and humidity. Light intensities range up to 2,800 foot candles and two pollutant concentrations can be controlled simultaneously from ambient to injury-causing levels.

APPARATUS

Chambers

The system consists of four plywood chambers, each 48 inches high, 48 inches deep, and 42 inches wide (fig. 1). The sides and bottom are made from 1/2-inch plywood. The front and back are framed with 1- x 6-inch boards set vertically to the bottom and sides. The openings in the front and back are closed by doors, each made of 1/2-inch plywood and held in place by eight horizontal-handle clamps. The seal between each door and the chamber is a gasket made from 1/4-inch i.d. Tygon[1] tubing glued to the chamber. The top of the chamber is covered with 5-mil Teflon[1] film held in place with furnace duct tape and wood cleats. The false floor in the chamber is 1/8-inch sheet aluminum supported 5-5/8-inches above the bottom of the chamber and has 1/4-inch holes in a 2- by 2-inch lattice. The inside of the chamber is painted with white epoxy paint to increase light intensity and prevent pollutants from reacting with the wood surface of the chamber. Each chamber sits on a wooden frame with the false floor of the chamber 36 inches above floor level.

Airflow system

The airflow system is a negative-pressure, single-pass system. The air mover is a high-pressure, belt-driven blower capable of drawing a static water pressure of more than 5 inches.

The blower is attached to a reinforced 8-inch furnace duct which is attached to each chamber by a 4-inch aluminum pipe that enters the chamber through the side but under the false floor. This section of pipe contains a butterfly valve to control airflow and an orifice plate with pressure-measuring taps on either side (Hinners, Burkart, and Punte 1968).

Air enters the chamber through two 4-inch aluminum pipes at the top of the chamber. The other end of these pipes are fastened to a sheet-metal plenum under the chamber. Each pipe has two pollutant inlets. The plenum contains a heater for warming the air, a steam inlet, and two 12- x 12- x 2-inch charcoal filters to clean the air. This plenum connects into another duct, common to all the chambers, and is attached to the outlet side of the air conditioning system. A particle filter is mounted on top of the air conditioning system to remove dust particles.

Air conditioning system

The air conditioning contains three individual compressor and evaporator coil units. The first is a 5-ton precooling system that lowers the temperature of the incoming air to about 5°C. The second and third units are 7.5-ton systems connected in parallel below the first unit. The air coming out of the second and third units at about -5°C causes them to ice up. They are alternately defrosted by passing hot gas through the evaporator coils. Each of the second and third units is large enough to supply cooled

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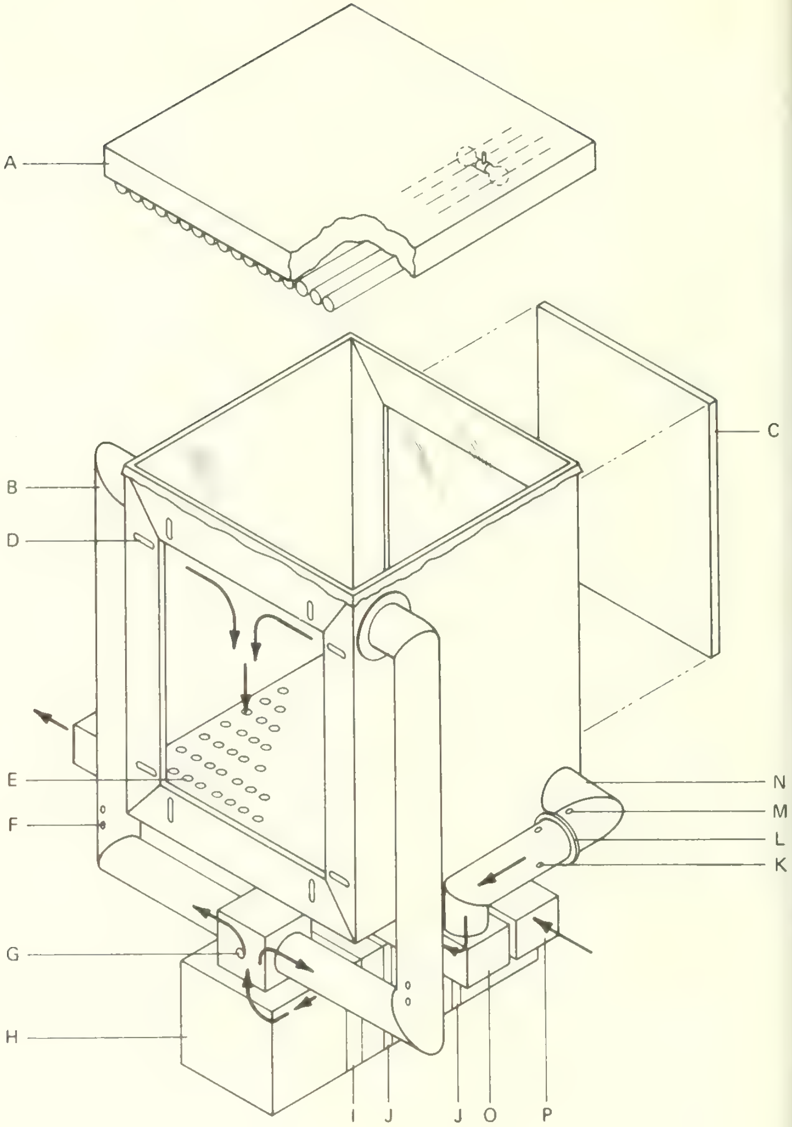
[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 1. View of chamber:

A, Light bank
B, 4-inch inlet duct
C, Door
D, Horizontal handle clamp
E, False bottom
F, Pollutant addition port
G, Steam addition port
H, 12-inch inlet duct
I, Heater
J, Charcoal filter
K, Butterfly valve
L, Orifice plate
M, Pressure tap
N, 4-inch aluminum outlet pipe
O, Exhaust duct to blower
P, Inlet duct from air conditioner.

Arrows show direction of air movement.



air to the entire system, so defrosting one unit does not influence the temperature or humidity in the chambers.

Light system

Over each chamber is a bank of twenty-four 48-inch VHO cool white fluorescent bulbs and eight 150-watt incandescent bulbs. Each bank is controlled by a 24-hour timer.

Six different light intensities can be provided by turning out the fluorescent bulbs in groups of four and by dimming the incandescent bulbs with a rheostat. The fluorescent bulbs are switched off systematically so that as the light intensity is reduced it falls uniformly throughout the chamber.

Temperature control system

Temperature is controlled with set-point controllers connected to shaded thermocouples in the chambers. The controller electronically compares the chamber temperature with the set-point temperature and regulates the heat accordingly.

The temperature in each chamber is independent of the others. Temperatures are recorded continuously on a multipoint recorder. Each chamber also has a programer that can vary the temperature over a 24-hour period. Six 12-inch bar heaters with radiating fins are used to heat each chamber.

Humidity control system

Humidity is controlled in the same manner as temperature. Lithium chloride humidity sensors, mounted in the chambers, are connected to set-point controllers. The controller electronically compares the humidity in the chamber with the set-point humidity and opens or closes a motorized needle valve to increase or decrease the amount of steam added to the air moving through the chamber. The humidity in the chambers is monitored continuously with a multipoint recorder.

Pollutant addition system

Two pollutants can be added individually or in combination to each chamber. The pollutants move under slight positive pressure through Teflon tubing to a stainless steel shut-off valve, then to a stainless steel micrometering valve. The gases then travel through more Teflon tubing to the two 4-inch aluminum pipes that enter the chambers. The pollutants are added to the air stream about 5 feet before it enters the chamber to allow ample mixing.

The pollutant concentration in each chamber is monitored by pulling an air sample from the chamber through Teflon tubing and a stainless steel solenoid into a manifold with a metal bellows pump. The pollutant monitors are attached to the manifold to sample the air stream and record the pollutant concentration on a strip chart recorder. The monitors are changed from one chamber to another by a static stepper that opens and closes the solenoid valves on the sample lines from the chambers. The desired pollutant concentration is obtained by observing the strip chart recorder and adjusting the appropriate micrometering valves.

PERFORMANCE

The chamber system has performed very satisfactorily. The airflow system allows as many as two complete air changes per minute. The airflow rate was determined by measuring the airflow through the 4-inch exhaust line with a hot-wire anemometer. The rates are calibrated against the pressure drop across the orifice plate in the exhaust line and the desired flow maintained by measuring the pressure drop and adjusting the butterfly valve in the air outlet line. The system is usually operated at one change of air every 2 minutes.

The light intensity in the chamber at 12 inches above the floor ranges from 2,800 foot candles at full light to 800 foot candles at 1/6 of full light with new bulbs. The light intensity decreases approxiately 20 percent from the center to the corners of the chamber. Consequently in selecting an experimental design, plants must either be placed in a replicated block design or moved periodically to reduce the effect of the nonuniform light intensity.

Temperature control is within acceptable limits. The temperatures in the center of the chamber and in each corner at 6 and 18 inches above the floor were within a range of ±1°C. The temperature can be held constant at any temperature between 15 and 35°C. with the set-point controllers, or varies over a 24-hour period with programmers.

Relative humidity can be controlled at any value between 25 and 95 percent with a variation of ±3 percent at 23°C. This variation was found when the humidity was measured in each corner 12 inches above the floor. At low temperatures, a relative humidity of 25 percent cannot be maintained because air cooled to 5°C. and reheated to 15°C. has a relative humidity of 45 percent even without the addition of any steam.

Air pollutants can be added in a wide range of concentrations ranging up to levels that cause acute injury. The concentrations can be maintained with slight adjustments for long periods.

Seedlings have been grown in the chambers for 3 months. Leaf color was good and height growth was comparable to that of seedlings in growth chambers.

The chambers have functioned both as growth chambers and fumigation chambers. They could easily be modified by putting windows and glove-box gloves in the doors so that closure of stomata, photosynthesis, or other physiological processes could be measured during fumigation.

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SEMTAP
(Serpentine End Match TApe Program)

The Easy Way to Program Your Numerically Controlled Router for the Production of SEM Joints

by Ronald E. Coleman

FOREST SERVICE RESEARCH PAPER NE-384
1977
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
6816 MARKET STREET, UPPER DARBY, PA. 19082

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Abstract

SEMTAP (Serpentine End Match TApe Program) is an easy and inexpensive method of programing a numerically controlled router for the manufacture of SEM (Serpentine End Matching) joints. The SEMTAP computer program allows the user to issue commands that will accurately direct a numerically controlled router along any SEM path. The user need not be a computer programer to produce a variety of SEM patterns.

Serpentine End Matching (SEM) is a new method of precisely end-joining short pieces of dimension lumber in an esthetically pleasing manner (Gatchell et al. 1977). SEM camouflages the end joint so well that, at best, the joint cannot be detected. The SEM joint is disguised as a part of the grain pattern of the two pieces of wood that are joined together.

Assuming that grain and color requirements are met, the acceptance or rejection of a SEM joint depends on how well the two curves that form the joint fit together. The manufacture of SEM joints requires a precise machining technique; this requirement is easily met by using a numerically controlled router.

A SEM joint is composed of many arcs that resemble a single continuous curve. Computing these arcs manually has been time consuming and impractical, but now this is unnecessary. With the aid of a computer any number of SEM patterns can be easily and inexpensively produced.

Numerically Controlled Routers

Numerically controlled routers are used primarily for continuous path machining, or contouring. Similarly controlled machines such as drills and boring machines are used in point-to-point operations. The basis for positioning or locating the points in both operations is the rectangular coordinate system; any point in a given plane is described by a unique set of coordinates in that plane.

The primary difference between contouring and point-to-point operations is the way the cutting tool moves from one point to another. The primary concern in point-to-point operations is the precise location of the points; the path from one point to another is irrelevant because it occurs outside of the work piece.

In contouring, the path between points is as important as the location of the points because the machining operation is continuous through and between these points. The path taken by the cutting tool between these points is determined by interpolation.

Three types of interpolation are used in numerically controlled routers: linear, circular, and parabolic. All numerically controlled routers perform linear interpolation, and many perform linear and circular interpolations; but only a few perform all three functions. Only linear interpolation is required if straight lines and a few simple curves are desired. However, if most of the routing is done in arcs and requires a close tolerance, linear interpolation is impractical. A combination of linear and circular interpolation will perform all but the most complex contouring jobs.

Complicated aerodynamic designs and free-form designs used by the automobile industry require expensive additional parabolic interpolation. Because providing parabolic interpolation in numerical control units is costly, only linear and circular interpolation were considered for manufacturing SEM joints.

When the same command points were used for linear or circular interpolation, the error that resulted from linear interpolation was almost eight times greater than that from circular interpolation. For precision, circular interpolation should be used as often as possible for describing SEM router bit paths.

As with any computer, the numerical control unit that directs the router is only as accurate as the instructions it is given. The control unit receives instructions from a perforated or punched tape. If the curves become the least bit complex, the trigonometric and geometric analogues become complicated. Because of the large number of computations and the increased chance for human error, computing SEM patterns manually is impractical.

SEMTAP (Serpentive End Match TApe Program) eliminates these problems; this FORTRAN program is very easy to use, and the user need not be a computer programer to produce a variety of SEM patterns quickly and inexpensively.

SEMTAP

Two paths are required to produce a SEM joint. If a router bit is moved through a piece of wood along a curved path, the two pieces of wood that are produced will not fit together because the rate of curvature is different for each piece of wood (Fig. 1). If the pieces are to fit, two router bit paths must be used—one on either side of the desired glue line (Fig. 2).

SEMTAP enables the user to issue commands that will accurately direct a numerically controlled router along any SEM path. SEMTAP uses the sine function to describe SEM joints; each SEM pattern requires a router bit path on either side of the sine wave. These paths must be parallel to the sine wave, and offset a distance equal to the radius of the router bit.

Only three pieces of information are required by SEMTAP to produce commands for each SEM pattern: the amplitude and period of the sine wave describing the SEM joint, and the radius of the router bit that will be used in cutting the joint. By changing the amplitude or period or both, a variety of SEM patterns can be produced. To obtain the required accuracy, measurements of the radius of the router bit must be within 1/1000 of an inch.

The printout by SEMTAP includes all of the necessary preparatory ("G") codes and miscellaneous ("M") command codes (Fig. 3). These commands can easily be transferred from the printout to a punched tape.

The following is a list of the G and M codes used in SEMTAP:

G01: Linear interpolation
G02: Clockwise circular interpolation
G03: Counterclockwise circular interpolation
G04: Dwell
G90: Absolute input mode (all X and Y values are measured from zero)
G92: Absolute offset (used to set starting point at zero)
G94: Inch per minute programing that permits feed speeds (speeds at which the router bit travels) to be read in direct inches per minute
M02: End of program
M04: Head up
M08: Head down

These commands may be indicated by different G or M codes in some control units; however SEMTAP could still be used as is, and proper substitutions could be made before the tape is punched. SEMTAP may also be altered to print desired codes directly.

The command points are printed in absolute mode, that is, all command points (represented by X and Y) are referenced to zero. In circular mode (G02 or G03), the radius components "I" and "J" are referenced to the previous command point; "I" is the distance in the X direction, and "J" is the distance in the Y direction from the center of the arc to the reference point. The

Figure 1.—If a router is passed through a piece of wood along a curved path. . .

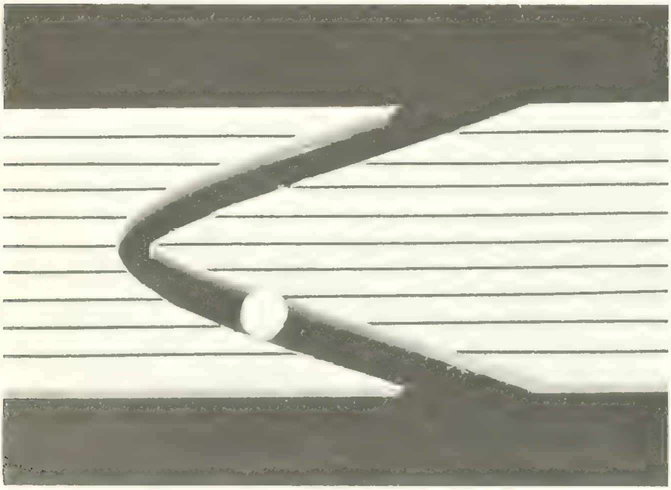


Figure 1A.—. . .the resulting pieces do not fit together.

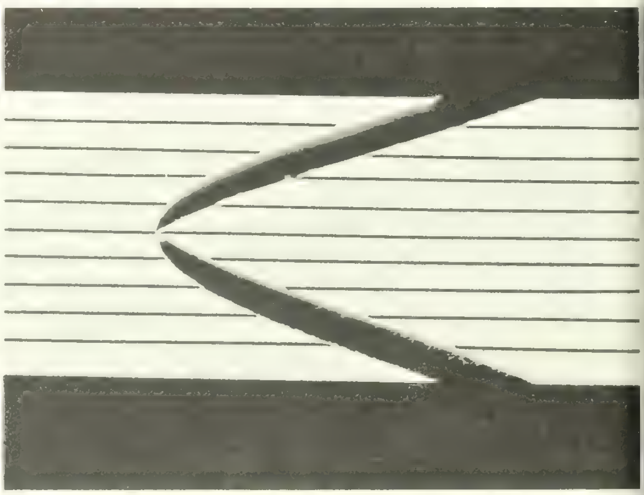


Figure 2.—Two router bit paths are necessary. . .

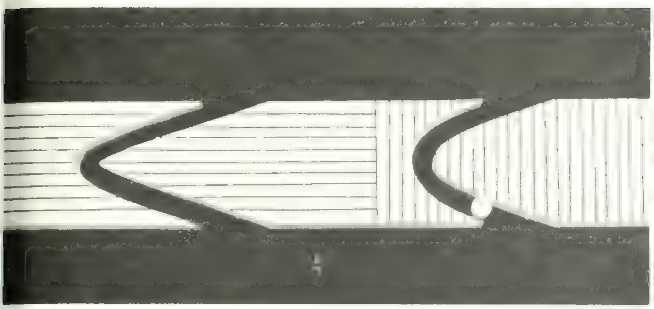


Figure 2A.—. . .if the pieces are to fit.

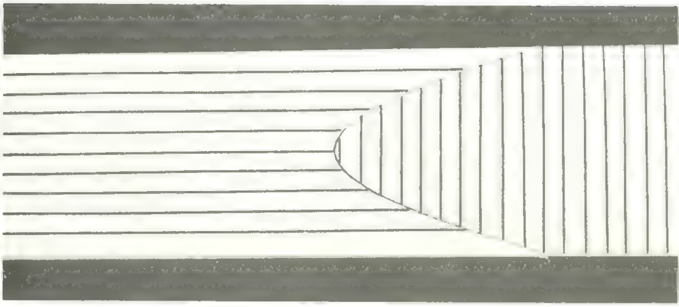


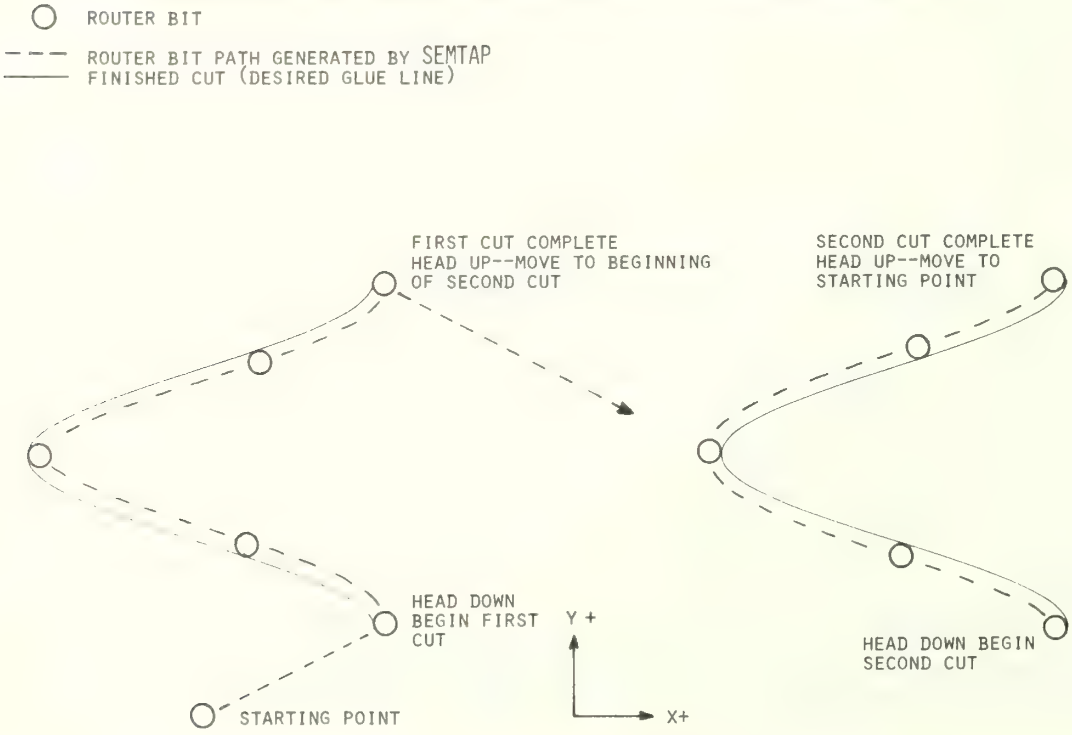
Figure 3.—Sample printout from SEMTAP that includes the necessary preparatory (G) and miscellanous (M) codes.

```
AMPLITUDE =  2.50  PERIOD =  5.00  BIT RADIUS =  0.250
G94G92X00000Y00000
G90
G01X  27500Y  12500F4000000
M04
G04F60000
G03X  26185Y  16039I  5730J   115F 458458
G03X  23286Y  18586I  9351J  7720F 970063
G03X  18114Y  21291I 18643J 29344F2000000
G03X   9270Y  24618I 43775J102951F2000000
G03X    758Y  27382I292718J884639F2000000
G02X -11190Y  31350I 96282J309936F2000000
G02X -18146Y  34237I 22498J 64030F2000000
G02X -21380Y  36201I  8169J 17097F1515838
G02X -22403Y  37268I  2672J  3582F 357490
G02X -22500Y  37500I   397J   299F  39748
G02X -22403Y  37732I   497J    71F  40181
G02X -21380Y  38799I  3431J  2262F 328805
G02X -18602Y  40531I 10428J 13634F1373228
G02X -11859Y  43405I 27177J 54416F2000000
G02X    -27Y  47368I 95540J265630F2000000
G02X    758Y  47618I113604J365132F2000000
G03X  12897Y  51650I 97609J314126F2000000
G03X  20380Y  54763I 24135J 68556F2000000
G03X  24118Y  56998I 10800J 22311F1982953
G03X  26460Y  59337I  6088J  8439F 832428
G03X  27500Y  62500I  4576J  3257F 449319
M08
G04F60000
G01X  82500Y  12500F4000000
M04
G04F60000
```

(Continued)

```
G03X   82245Y   12961I   730J   115F  59092
G03X   80530Y   14414I  5410J  4642F 570310
G03X   76113Y   16709I 15887J 25173F2000000
G03X   67667Y   19882I 41775J 98369F2000000
G03X   59242Y   22618I291115J879903F2000000
G02X   47103Y   26650I 97799J314701F2000000
G02X   39620Y   29763I 24205J 68729F2000000
G02X   35493Y   32299I 10402J 21570F1915790
G02X   33288Y   34732I  5799J  7483F 757376
G02X   32500Y   37500I  4705J  2836F 439511
G02X   33288Y   40268I  5497J    71F 439816
G02X   35493Y   42701I  7740J  4799F 728571
G02X   39094Y   44969I 13555J 17536F1773148
G02X   46407Y   48095I 29481J 58853F2000000
G02X   58456Y   52132I 97275J270319F2000000
G02X   59242Y   52382I112087J360368F2000000
G03X   71190Y   56350I 96093J309362F2000000
G03X   78146Y   59237I 22428J 63856F2000000
G03X   81124Y   61002I  8566J 17837F1582991
G03X   82336Y   62163I  3094J  4434F 432540
G03X   82500Y   62500I   452J   430F  49888
M08
G04F60000
G01X00000Y00000F4000000
M02
```

Figure 4.—Machining sequence for manufacture of SEM joint.



feed speeds prefixed by "F" are in inches per minute.

The numerical control format for X and Y is 3.4; this means that the first three places are to the left of the decimal, the last four places are to the right. Decimal points are not printed—the number 16220 is read by the numerical control unit as 1.6220. The format for F is 3.4; the format for I and J is 2.4.

The set of commands produced by SEMTAP directs the numerically controlled router to make two cuts (Fig. 4); the first cut produces the concave part of the SEM joint; the second produces the convex part. From the starting point—zero—the router bit is moved to the point where the first cut begins. The router bit is then lowered into cutting position and the first cut begins. After the first cut is completed, the router bit is raised and moved to the point where the second cut begins. Although we used an offset of about 6 inches from the beginning of the first cut, any offset is possible. After the second cut, the router bit is raised and is returned to the starting point. This completes the cycle.

SEMTAP is written so that the feed speeds are determined by the length of the radii of the arcs describing the router bit path. The longer the radius, the faster the feed speed (up to a maximum of 200 inches per minute). This is a logical way of determining feed speeds because large circles can be machined at a faster rate than small circles on a numerically controlled router.

At higher feed speeds, a "reader-bound" condition may occur; this is when the tape reader of the control unit is unable to read the commands as fast as they are being carried out. The reader-bound condition results in unprogramed pauses during the machining operation, but these pauses can be eliminated by lowering the feed speeds.

The cost of SEMTAP is moderate; when SEMTAP has been used with an IBM-370 computer, costs were always less than $1 per run.

Summary

- SEMTAP is easy to use, Each set of commands requires only a knowledge of the amplitude and period of the desired sine wave, and the radius of the router bit.
- SEMTAP is accurate. If the radius of the router bit is measured to within 1/1000 inch, the commands produced by SEMTAP will provide all of the information needed to produce acceptable SEM joints.
- SEMTAP is inexpensive—less than $1 per run on an IBM-370 computer.

Additional information about SEMTAP or SEM may be obtained from the USDA Forest Service, P.O. Box 152, Princeton, West Virginia 24740. A program listing of SEMTAP also is available upon request.

Literature Cited

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PROCESSING MAPLE SYRUP WITH A VAPOR COMPRESSION DISTILLER: AN ECONOMIC ANALYSIS

by Lawrence D. Garrett

FOREST SERVICE RESEARCH PAPER NE-385
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
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ABSTRACT

A test of vapor compression distillers for processing maple syrup revealed that: (1) vapor compression equipment tested evaporated 1 pound of water with .047 pounds of steam equivalent (electrical energy); open-pan evaporators of similar capacity required 1.5 pounds of steam equivalent (oil energy) to produce 1 pound of water; (2) vapor compression evaporation produced a syrup equalin quality to that from a conventional open-pan evaporation plant; and (3) a central plant producing 8,000 gallons of syrup per year should yield a return of 16 percent on investment. Increasing annual product output should increase the return on investment.

INTRODUCTION

MAPLE SYRUP is made by boiling down maple sap to remove water. The basic technique has changed little in 200 years. Evaporators have been improved and they are significantly more efficient than the methods used by early colonists, but the basic method of removing water is the same: application of direct heat to an open vessel or, in engineering terms, a single-effect system. This does not mean that the current evaporation method using flue pans is not acceptable; according to existing research and industry technology it is the only acceptable method. But the single-effect open-pan evaporator is only marginally economic. Oil-fired evaporators, the predominant type, require 3 to 4 gallons of oil for each gallon of syrup they produce. Their steam efficiency equivalent is 1.5 : 1; that is, they require 1.5 pounds of steam energy equivalent to evaporate 1 pound of water.

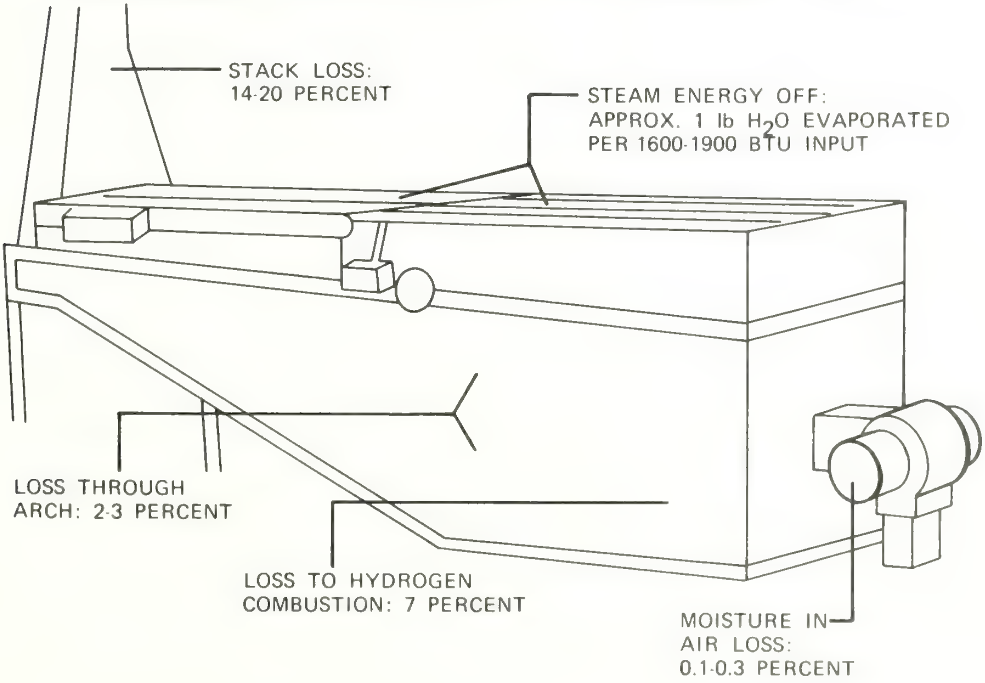
In 1976 the cost of processing a gallon of syrup on an oil-fired open-pan evaporator was approximately $3.60. Our studies indicate that 40 percent of the processing cost is for fuel. And 63 percent is accounted for by a combination of fuel, labor, and miscellaneous direct costs. Only 37 percent is for amortized capital costs, leaving little flexibility for realizing economies of scale with this technology.

Today, there is no commercial maple operation in the United States producing syrup continuously by any method other than open-pan evaporation. Yet, there are other possible ways of concentrating sap to a higher sugar content. These include flash evaporation, thermal evaporation under vacuum, mechanical compression distillation, reverse osmosis, ultrafiltration, and freeze drying.

Mechanical compression distillation has been used for desalinating salt water since World War II, but its potential for processing maple sap has not been previously investigated.

To study that potential, we tested a factory-designed desalination unit, established parameters for redesign, and evaluated a redesigned prototype for processing maple syrup.

Figure 1.—Conventional oil-fired maple syrup evaporator. Evaporator efficiency = 100-[16 + 2.5 + 7.0 + 0.2] 100-25.7 = 74.3.



Comparing processing technology

The engineering and economic efficiency of mechanical compression distillation can best be demonstrated by direct comparison with conventional open-pan evaporation.

In the open-pan evaporator (Fig. 1), heated gases and steam produced during the process are not recycled or reused. The efficiency of the system cannot exceed 1 : 1—1 pound of steam produces 1 pound of water. In actual field operation it requires 1.3 to 1.5 pounds of steam to produce 1 pound of water.

Mechanical compression distillers differ significantly from conventional maple syrup evaporators in that nearly all the heat energy developed is kept in the equipment.

The sap is preheated in a heat exchanger that absorbs heat from the distillate made in the evaporation chamber (Fig. 2). Sap is fed into the evaporation chamber at 212°F, having approximately 1,100 Btu per pound. The solution is sprayed over a tube bundle with a surface temperature of 228°F. The thin spray on the tubes at that temperature differential creates a flashing effect and allows maximum heat transfer. Flashing vaporizes water molecules, which are pulled from the evaporation chamber at a negative pressure of approximately 1/2 pound per square inch. The vapor passes through a mechanical compressor, increasing its temperature to 228°F and heat yield to 1,150 Btu per pound. The vapors are forced into the tube bundle, and the continuing spray of sap cools the vapors to make distilled water.

The distillate is passed through the plate heat exchanger, releasing its heat to the incoming sap, and passes out of the equipment as water. The syrup passing down through the tube bundle into the sump is also led through the heat exchanger to transfer its heat to incoming sap. If the syrup is not of the desired concentration, it is recirculated with the incoming feed over the tube bundles.

Starting the equipment requires heat for the plate heat exchanger and the tube bundle. This is provided by electric heaters. During operation, the heaters are used only intermittently as heat is needed.

THE STUDY

Test Series 1: Evaluation for redesign

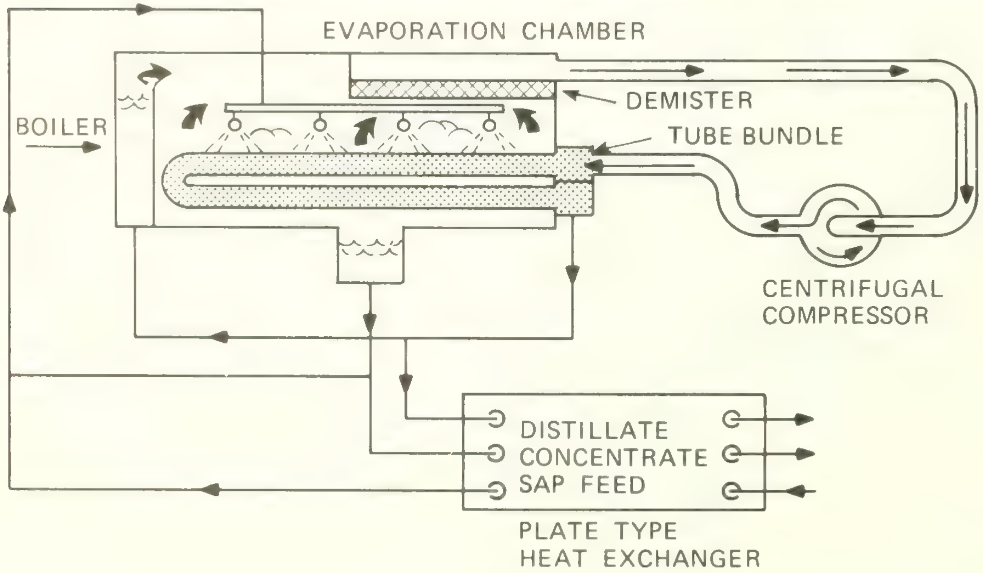
Tests of a standard vapor-compression distiller[1] showed that maple sap can be concentrated to 66°Brix maple syrup of acceptable quality.

---

[1] Spray-Film® vapor compression distiller (VCD), model S-600 spec-E, bulletin 750-1015, manufactured by Aqua-Chem, Inc., Milwaukee, Wis.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an offical endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 2.—Schematic of original vapor compression distiller.



Three concentrates were produced from 2.5°Brix sap in Test Series 1: 20°Brix concentrate, 40°Brix concentrate, and 66°Brix syrup. The equipment was operated a total of 80.8 hours, 5.5 hours for the first, 49.8 hours for the second and 25.5 hours for the final 66°Brix concentration.

However, as the equipment tested was specifically designed to produce a constant distillate (5 percent saline solution), the compressor had fixed output capacity. As the viscosity and boiling point of the syrup increased, tube fouling increased and production capacity was reduced.

Tube fouling reduced production capacity most above 40°Brix. At 66°Brix, fouling of the tube bundles decreased the coefficient of heat exchange significantly. Distillate production dropped from 628 gallons per hour at 20°Brix to 523 gallons per hour at 40°Brix. The most significant drop, to 285 gallons per hour, occurred at 66°Brix (Table 1).

The energy required to process maple concentrates with the unmodified mechanical compression evaporator increased significantly with level of concentration. Electric power consumption of 1.4 kWh was required to concentrate 1 gallon of 2.5°Brix solution to 20°Brix. Increasing the concentration increased the power requirements. At 66°Brix, 4.2 kWh were required for each gallon of syrup concentrate produced. At a cost of $.025 per kWh, energy cost $0.04 per gallon to concentrate 20°Brix solution, $0.06 for a 40°Brix concentrate, and $0.125 for a 66°Brix concentrate, or maple syrup.

Quality

Vapor compression distillers should produce good quality syrup. Concentrate is never exposed to a surface temperature exceeding 228°F, whereas exposure to 500 to 700°F surface temperature is common in a conventional evaporator. Analysis of sap, syrup, and distillate in Test Series 1 revealed that syrup produced from the unmodified VCD was similar in quality to syrup produced from the same sap in an open-pan evaporator. However, because the sap delivered to the research site was of poor quality, the syrup did not exceed "C" grade from either the conventional or VCD unit. Bacteria counts in the sap exceeded 3 million per millimicron; this resulted in high levels of invert sugars, phenols, and amino nitrogen, causing darker color and stronger flavor. (Normal bacteria count of sap at the tap hole is 300 to 1,000 per millimicron.)

Redesign of the VCD

To increase the efficiency of the VCD unit on more viscous solutions, it was redesigned for products ranging from 55°Brix to 65°Brix.

To minimize the effects of the higher boiling point and viscosity of the 66.5°Brix syrup, the redesigned system concentrates the syrup in two steps. The dilute solution entering the system is preheated in a heat exchanger that absorbs the heat from the newly made distillate (Fig. 3). The feed is then introduced into the recirculation loop of the first concentration step, where a part of the liquid is vaporized when it comes in contact with the heating bundle. The

Table 1.—*Performance of 600 gal/h [a] mechanical vapor compression distiller processing 2.5° Brix maple sap to three concentrations.*

°Brix of concentrate	Sap feed rate	Recirculation temperature	Product temperature	Product output		Distillate output	kWh/gal produced
	gal/h	°F		*gal/h*	*lb/h*	*gal/h*	
20	735.9	210	58[b]	107.4	999.6	628.5	1.4
40	558.0	212	211	34.7	347.0	523.3	2.0
66	294.5	217	217	8.6	94.6	285.9	4.2

[a] Rated at 600 gal/h for 0.5% salt solution.
[b] Product initially recirculated through plate heat exchanger to extract heat from solids.

Figure 3.—Schematic of redesigned vapor compression distiller.

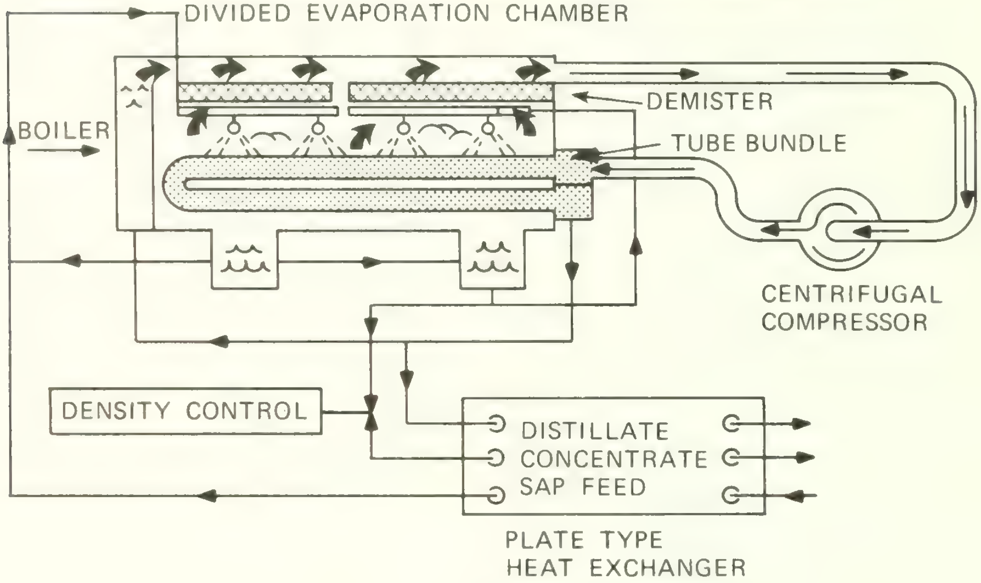
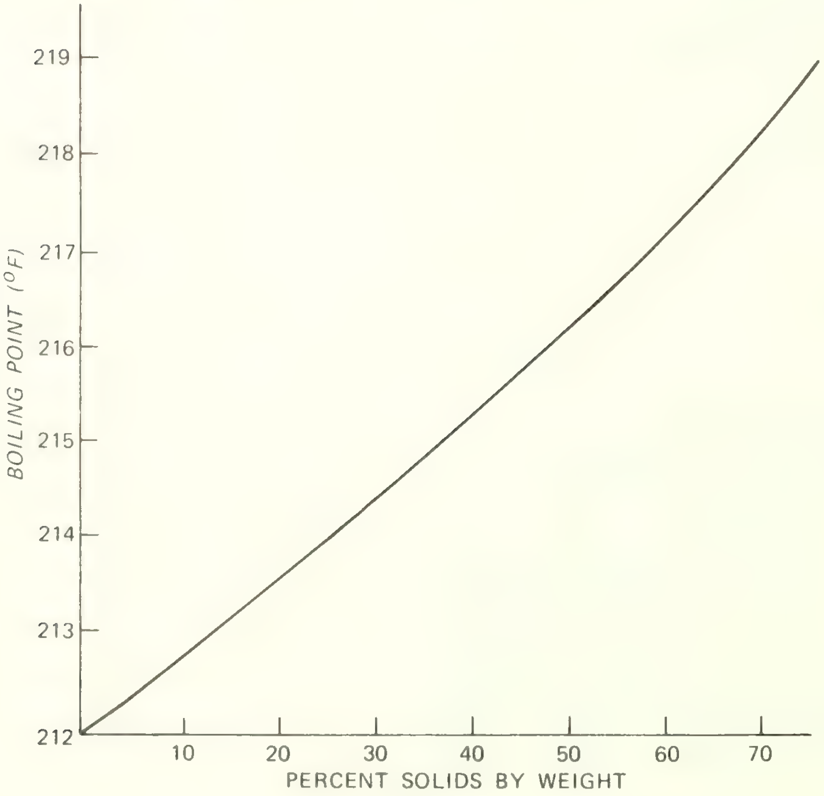


Figure 4.—Effect of syrup density on boiling point of maple syrup.



syrup then passes by gravity to the second concentration step, where it reaches the desired concentration. The concentration is discharged from the system by a pump.

The water vapor generated from the two sections is combined and passed through a wire mesh demister to remove any entrained droplets. The vapor is then compressed and piped to the inside of the heat tubes. In the heating bundle the hot vapor is condensed by the cooler concentrate on the outside of the tubes, thus giving up its latent heat of vaporization and most of the energy required to evaporate an equivalent amount of feed solution. The condensed vapors are collected as distillate and pumped to the heat exchanger. Heat is transferred to incoming sap as the distillate leaves the system.

Heat lost to the environment by radiation and convection, and incomplete heat exchange, require that a small amount of heat be continually added to the system to prevent a vacuum from forming in the shell. This heat is added by electric heaters located in a boiler that reboils a small portion of the distillate. Since the boiler is directly connected to the steam chest, the small amount of vapor produced is at the same pressure as the vapor inside the tube bundle (about 3 to 4 lb/in²g). The boiler contains four heaters, all of which are used in starting. During normal operation a pressure switch on the shell turns one heater on and off to maintain the correct pressure.

Not only does the boiling point increase as the sap is concentrated, requiring more heat and thus lowering efficiency (Fig. 4), but also less steam is produced per unit volume of liquid passing over the tube bundle, reducing total heat transfer per unit volume.

These problems were solved in the redesigned equipment by dividing the tube bundle into two evaporating surfaces. The first surface, 60 percent of tube bundle, handled concentrates up to 40 percent solids, creating sufficient steam volume to maintain a high heat transfer for the higher concentrations being sprayed over the remaining 40 percent of the surface. Two larger sumps replaced the original one (Fig. 3).

The evaporation efficiency of the redesigned VCD is 21.0 when concentrating to 66°Brix. Evaporating efficiency is not affected by changes in the sugar content of incoming sap concentrate. That is, a change of 1.5 to 3.0°Brix changes the sap-to-syrup ratio but has an insignificant effect on distillate flow and Btu requirements (Table 2). This improvement significantly increased operating efficiency over that of the standard design.

Changing syrup concentration from 50°Brix to 66°Brix reduces evaporating efficiency (Table 3). Less heat energy is used per hour (240 versus 248 Btu), but there is a drop in distillate production from 5,675 to 5,050 lb/h, a 13-percent reduction that outweighs the 8-Btu energy saving and reduces evaporating efficiency from 22.9 to 21.0.

The drop in evaporation is caused primarily by increased concentration and reduced boil-off per unit flow. Each unit of boil-off requires more Btu, but the reduced rate actually lowers the total kWh requirement.

The drop in evaporating efficiency at higher viscosities also reduces hourly syrup production from 29.1 gallons (from 2.5°Brix sap) at 50°Brix concentration to 18.8 gallons (from 2.5°Brix sap) at 66.5°Brix concentration. This demonstrates the capability of the equipment to increase production significantly during maximum sap flows. A more stable partial concentrate (i.e. 40 to 50°Brix) can be produced at times of peak flow and stored for final processing later.

Table 2.—*Operating characteristics of redesigned vapor compression distiller at various sap concentrations.*

Sap concentration	Sap input	Syrup output at 66.5°Brix		Total processing cost per gallon of syrup
°Brix	------*gal/h*-----		*lb/h*	
1.5	5167	10.6	117	$5.17
2.0	5216	15.1	166	3.64
2.5	5259	18.9	209	2.44
3.0	5303	23.0	253	2.38

Distillate output: 5050 lb/h; heat equivalent: 240 Btu/h; evaporating efficiency: 21.0.

Table 3.—*Evaporating efficiency of redesigned vapor compression distiller producing various maple syrup concentrates.* [a]

Product concentration	Sap input concentration	Flow rates				Annual syrup production (in 360 h)	Electric power input				Equivalent heat input	Evaporating efficiency
		Sap	Distillate	Syrup at 60°F	Syrup at 60°F		Compressor at motor	Heaters	Pumps at motors	Total		
°Brix	*°Brix*	*lb/h*	*lb/h*	*lb/h*	*gal/h*	*gal*	*kW*	*kW*	*kW*	*kW*	*Btu/h*	
50	1.5	5851	5675	176	17.1	6,160	43.4	23.7	5.7	72.8	248	22.9
	2.0	5911	5675	236	23.0	8,280						
	2.5	5974	5675	299	29.1	10,500						
	3.0	6037	5675	362	35.2	12,700						
55	1.5	5680	5525	155	14.7	5,290	42.7	23.7	5.7	72.1	246	22.5
	2.0	5733	5525	208	19.7	7,090						
	2.5	5778	5525	263	25.0	9,000						
	3.0	5844	5525	319	30.3	10,900						
60	1.5	5487	5350	137	12.7	4,570	42.0	23.7	5.7	71.4	244	21.9
	2.0	5534	5350	184	17.1	6,160						
	2.5	5583	5350	233	21.7	7,810						
	3.0	5632	5350	282	26.2	9,430						
66	1.5	5167	5050	117	10.5	3,780	41.0	23.7	5.7	70.4	240	21.0
	2.0	5216	5050	166	14.9	5,360						
	2.5	5259	5050	209	18.8	6,770						
	3.0	5303	5050	253	22.8	8,210						

[a] Assumptions: Heat transfer coefficient: 80%; Sap entering heat exchanger at 40°F; Evaporation rate independent of feed concentration; Compressor and pump motors have 91% efficiency; Syrup product does not pass through heat exchanger; Heaters rated at 23.7 kW.

There is little change in power consumption with changes in flow. As related, decreasing the density of syrup from 66.5 to 50°Brix decreases power consumption by only 2.4 kWh (72.8 to 70.4). The electric motors and heaters that drive the system are not designed for variable power usage, so running at lower concentrations changes flow but has little effect on energy requirements.

The redesigned VCD prototype required only 0.047 pounds of steam equivalent per pound of distillate produced. This compares to 1.5 pounds of steam in a conventional maple syrup evaporator and 1.1 pounds in the most efficient single-effect boilers. Based on these data, the evaporating efficiency of the vapor compression system tested was 21 $\frac{1.000}{0.047}$, as compared to .65 $\frac{1.0}{1.5}$ for the conventional open-pan evaporator. In other words, the evaporating efficiency of vapor compression is 32 times that of the conventional open-pan evaporator.

Product Quality

Maple syrup from test runs of the redesigned VCD unit was similar in quality to syrup from a conventional evaporator. Tables 4 through 6 include statistics on sap, syrup, and distillate samples from the redesigned prototype.

Syrups produced by the redesigned VCD unit were rated good to excellent in flavor and "B" in color. Analyses showed some differences between these samples and a random sample of "B" syrups produced by conventional evaporators (Table 5) but these differences do not indicate major differences in the product. The syrups are similar in sucrose level and pH. The higher average of invert sugars in syrups from the conventional evaporator relates to the higher phenol count. Although the amounts of metal salts differ in the two syrups, both are well within FDA acceptable levels. In short, the syrups produced by the VCD and conventional evaporator are of similar quality.

Table 4 presents analyses of the sap used to make the syrup samples in the VCD unit. The sap was 46 hours old and had a temperature of 62°F when processed into syrup. Time, temperature, and numerous transfers of the sap could have contributed to the high phenol and amino nitrogen counts, which contribute to the darker color and stronger flavor of "B" grade syrups (University of Vermont 1973).

Table 4.—*Analysis of sap processed into maple syrup concentrates in redesigned vapor compression distiller (six samples).*

Statistic	Metal salts				pH	Sucrose	Invert sugar	Phenol	Amino nitrogen
	Fe	Pb	Cu	Zn					
	p/m	*p/m*	*p/m*	*p/m*		%	%	*p/m*	*p/m*
Mean	0.578	0	0.198	1.150	6.330	2.370	0.400	18.180	1.600
Standard deviation	.749	0	1.76	0.055	.197	0.234	.089	1.863	0.447
Variance	.561	0	.031	.003	.039	.055	.008	3.470	.200

Table 5.—*Comparison of syrup samples produced from conventional evaporator and vapor compression distiller.*

Statistic	Metal salts				pH	Sucrose	Invert sugar	Phenol	Amino nitrogen	Syrup grade
	Fe	Pb	Cu	Zn						
	p/m	*p/m*	*p/m*	*p/m*		%	%	*p/m*	*p/m*	
	CONVENTIONAL EVAPORATOR[a]									
Mean	16.03	.34	1.68	24.26	6.66	61.23	6.08	1,096.23	325.11	B
Standard deviation	8.50	.54	1.25	8.97	.25	3.25	4.32	176.44	41.23	B
Variance	72.25	.29	1.56	80.57	.06	10.50	18.68	31,131.00	1,699.91	B
	VAPOR COMPRESSION DISTILLER[b]									
Mean	2.20	5.50	2.44	10.30	6.63	61.77	2.01	1,010.41	255.00	B
Standard deviation	0.37	0.70	0.52	2.50	0.19	4.45	0.41	168.33	47.67	B
Variance	0.14	0.49	0.27	6.26	0.04	19.78	0.17	28,335.35	2,272.58	B

[a] 13 samples

[b] 13 samples

Table 6.—*Analysis of five distillate samples from maple sap processed in redesigned vapor compression distiller (in parts per million).*

Statistic	Mineral salts				Metal salts	pH	Phenol	Amino nitrogen
	Na	K	Ca	Mg	Cu			
Mean	.10800	.02600	.1160	.01800	.08800	5.660	3.28	.178
Standard deviation	.01300	.00500	.0170	.00400	.00400	0.114	1.06	.083
Variance	.00017	.00003	.0003	.00002	.00002	0.013	1.13	.007

All values 0 for Fe, Mn, Zn, Pb, Sn, ed, sucrose, and invert sugar.

It is not possible to compare the characteristics of syrup produced by the VCD unit with a standard because no standard exists. All the characteristics studied varied widely in a cross section of syrups from conventional evaporators, and the VCD syrup was well within the limits of these values. We believe that with a higher quality sap the VCD unit would produce a higher quality syrup.

The other product of the VCD is distilled water. Analysis of samples showed it to be of high quality. None of the metal or mineral salts exceeded 0.1 ppm and a low phenol count indicated minimal contamination.

Economic effectiveness

The economics of vapor compression processing and its level of application are affected by several production factors unique to the maple industry:

- Maple sap is high in unit weight (8.5 lb/gal) but low in unit value ($0.104/gal).
- Maple sap is geographically dispersed so that its transfer cost increases significantly as the distance from tree to plant increases. As the processing plant gets larger, the procurement zone becomes larger, increasing the unit cost of sap.
- The volume ratio of raw material (sap) to product (syrup) is 36 to 1. Consequently, costs are incurred for 97 percent of the resource volume which is later discarded.
- The production period is limited to 8 to 12 weeks, or only 15 to 20 percent of the annual production period available for many processed foods. This forces a large plant to increase output per hour to provide a production base over which to spread larger capital costs.
- Maple syrup processing requires considerable energy for water evaporation and the development of color and flavor. Energy is fast becoming the highest cost input in food processing.

The availability of maple sap in a plant's procurement zone may fluctuate as much as 30 percent from one year to another because of weather alone. This is crucial for plants that require heavy capital investments and, therefore, high annual amortization. Even taking into account all of the above constraints, a vapor compression plant affords greater return on invested capital than the conventional maple syrup processing system. The reason is its significantly lower processing cost per unit of production.

Tables 7 and 8 show estimated annual operating costs for a vapor compression plant and a conventional plant. The estimated annual cost for the VCD plant is $2.44 per gallon of syrup produced; significantly lower than the annual cost of $3.60 per gallon for the conventional system.

These economic evaluations of the two plant designs treat all future costs as though they were incurred today. They do not consider the time value of money. Yet they do give a realistic economic evaluation of the two investment opportunities. All capital investment is amortized at 10 percent for the time periods indicated. Operating costs are current expected costs of operating the plants. With conventional evaporation, approximately 63 percent of the processing costs are operating or direct costs—energy, labor, and materials. Only 37 percent are capital or fixed costs (Table 8). Consequently, increasing production has little effect on unit costs.

The opposite is true of a vapor compression plant: The physical plant is costly but efficient. Capital costs are 87 percent of total processing costs, whereas operating costs are only 13 percent (Table 7). Therefore the greater the production, the lower the unit cost of production.

The main costs of a VCD plant are capital costs; the plant will incur these costs regardless of production level. Potential investors should be aware that decreases in production due to weather or plant failure will increase unit cost.

A VCD plant designed for 7,000 to 9,000 gallons annual production can sustain a production cut of 35 percent and still produce syrup at a processing cost comparable to that of a conventional plant. A 66°Brix maple syrup can be produced for $2.38/gallon at a production level of 8,210 gallons (Table 1). Reducing the production level 18 percent to 6,770 gallons increases unit cost to $2.88. A reduction of 35 percent to 5,360 gallons will increase unit cost to $3.64, or approximately that of a conventional evaporator.

Table 7.—*Total annual costs for a vapor compression maple syrup processing plant producing an average of 8,000 gallons per year.*

Cost item	Cost	Useful life	Annual cost	Percent of total
Capital costs [a]				
Building	$ 6,798	20	$ 744.38	
Sap storage (32,000 gal @ $.60/gal)	19,200	20	2,102.40	
Syrup storage (7,000 gal @ $2/gal)	14,000	20	1,533.00	
PCVC 850	106,000	20	11,607.00	
Equipment	9,900		1,084.05	
Total	$155,898		$17,070.83	87
Operating costs				
Electricity— 70.4 kW x 403 h @ $.05/kWh			$1,418.56	
Operating and routine maintenance— 114 h @ $3/h			342.00	
Cleaning chemicals— $60/wash x 3 washes season			180.00	
Annual maintenance supplies			448.00	
Annual preparation and maintenance labor— 27 h @ $3/h			81.00	
Total			$ 2,469.56	13
Total annual costs			$19,540.39	100
Annual processing cost/gallon				$2.44

[a] Capital costs amortized at 10 percent.

Table 8.—*Annual capital and operating costs for conventional open-pan evaporator plant producing an average of 750 gallons per year.*

Cost item	Cost	Useful life	Annual cost	Percent of total
Capital costs				
Building	$1,820	25	$ 151.16	
Plant equipment	6,738	20	791.72	
Total	$8,558		$ 942.88	37
Operating costs				
Labor (hired) @ $3/h.			$ 400.00	
Fuel (oil and gas) @ 43c/h			1,128.75	
Electricity and miscellaneous			50.00	
Total			$1,578.75	63
Total annual costs			$2,521.63	100
Annual processing cost/gallon				$3.36

Return on investment

A study by Huyler of 14 conventional plants in the Northeast revealed that they return 10 to 14 percent on invested capital.[2] Producers studied did not approach the size of the plant studied here. However, studies by Kearl (1970), Acker and others (1970), and Pasto and Taylor (1962) indicate that the cost structure of the conventional plant permits little reduction in unit cost with increased size.

To evaluate return on investment for a VCD plant, a series of cash flows were developed to represent expected annual costs and returns. The data were developed to compare the expected returns from a VCD plant selling its product wholesale with those of a plant selling at retail (Figs. 5 and 6). The ROI analysis is based on a capital plant investment of $150,000, which includes equipment, buildings, storage tanks, and installation costs. Syrup production ranges from 6,770 gallons in year 1 to 9,000 gallons in year 20 for both analyses. Sap prices start at $.10 per gallon in year 1 and go to $.25 per gallon in year 20. All operating costs such as management, labor, fuel, materials, etc. are subject to an inflation rate of 5 percent per year. Also, each analysis contains an expensed investment for land in year 1.

Revenue cash flows for the two investments differ. Revenues for the plant that wholesales its product are based on a wholesale price ranging from $0.60 to $0.70 per pound in year 1. The plant that retails its product receives from $0.90 to $1.09 in year 1. However, to obtain that higher revenue, the plant is assessed a marketing cost equivalent to 20 or 30 percent of its gross revenues. Net revenues from both plants are further reduced by a 50 percent tax on net income.

Depreciation of capital investment is computed by the sum of year digits method (Parks 1973). This method was selected to reduce the impact of income tax liability in the early years of the investment. Ten years was selected as the length of the depreciation schedule to accommodate IRS regulations concerning agriculture equipment.

The analysis did not include investment credit on new equipment purchases. That credit would improve the return, but it is not equally available in all maple-producing regions.

The most critical factors in the analysis are the production period and the size of the operation. Twenty-five thousand taps are necessary to supply sufficient raw material to the plant, requiring a 60,000-gallon storage capacity at peak periods. Sap costs are computed f.o.b. the plant at $0.10, $0.11, and $0.12 per gallon of 2.5°Brix solution.

Maximum holding time for sap was set at 72 hours to minimize degrade. This limitation, applied to a probability distribution of small and large runs during an 8-week season, reduces the potential operating period. To compensate for the probability of bad seasons during the early years of operation, the plant is scheduled to produce only between 6,700 and 7,200 gallons, or operate only 360 hours per year. The run is expected to increase from 15 days (360 hours) the first year to 20 days (480 hours) in year 20.

Returns to the plant owner who wishes to wholesale his product (Fig. 5) will be less than if he retailed the product at a higher price (Fig. 6); he will receive a return on invested capital of from 10 percent at $0.60/lb. to 16 percent at $0.70/lb.

A plant owner who decides to retail can expect to invest $150,000 today and earn 12 to 18 percent interest over the next 20 years (Fig. 6). If he can borrow capital at a rate of 8 to 10 percent, he can expect to return 4 to 8 percent to management. The wholesaler will obviously earn less return (Fig. 5) but his venture should return 2 to 6 percent to management.

CONCLUSIONS

Several conclusions can be drawn from these analyses:

- Vapor compression distillation can produce maple syrup of the same quality as that produced by a conventional evaporator. Both metal and mineral salts are within the concentrations expected in syrups from open-pan evaporators.
- VCD equipment will also produce a distilled water that exceeds pharmaceutical quality standards for certain grades.
- The VCD equipment tested was 32 times as efficient as conventional open-pan evaporators. Whereas 1.5 pounds of steam equivalent are

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[2] Huyler, Neil K. 1976. Cost and return estimates for maple syrup operations. Unpublished report on file at George D. Aiken Sugar Maple Laboratory, Burlington, Vt.

Figure 5.—Analysis of economic return on VCD plant investment at various levels of wholesale syrup price and sap cost.

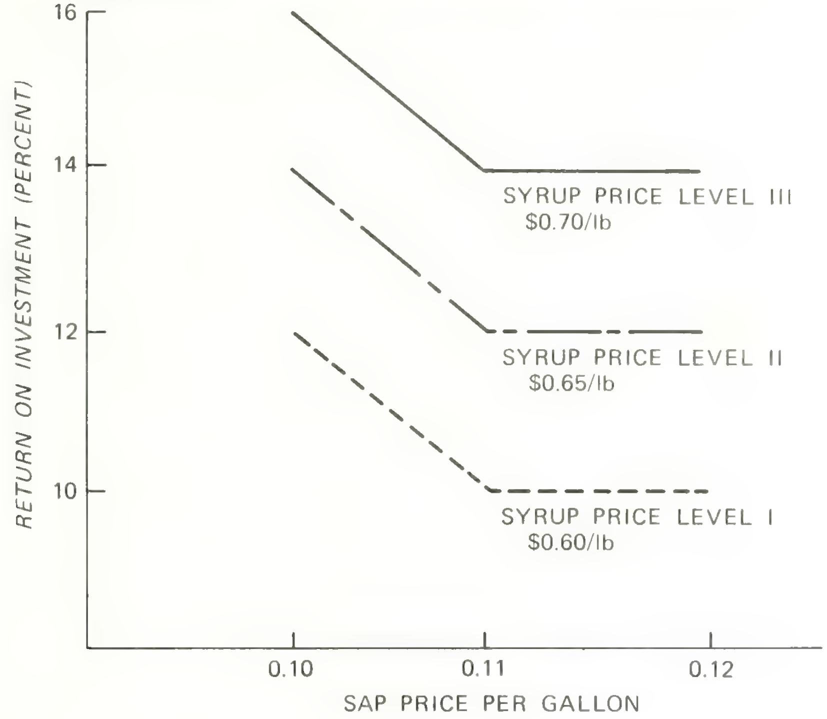
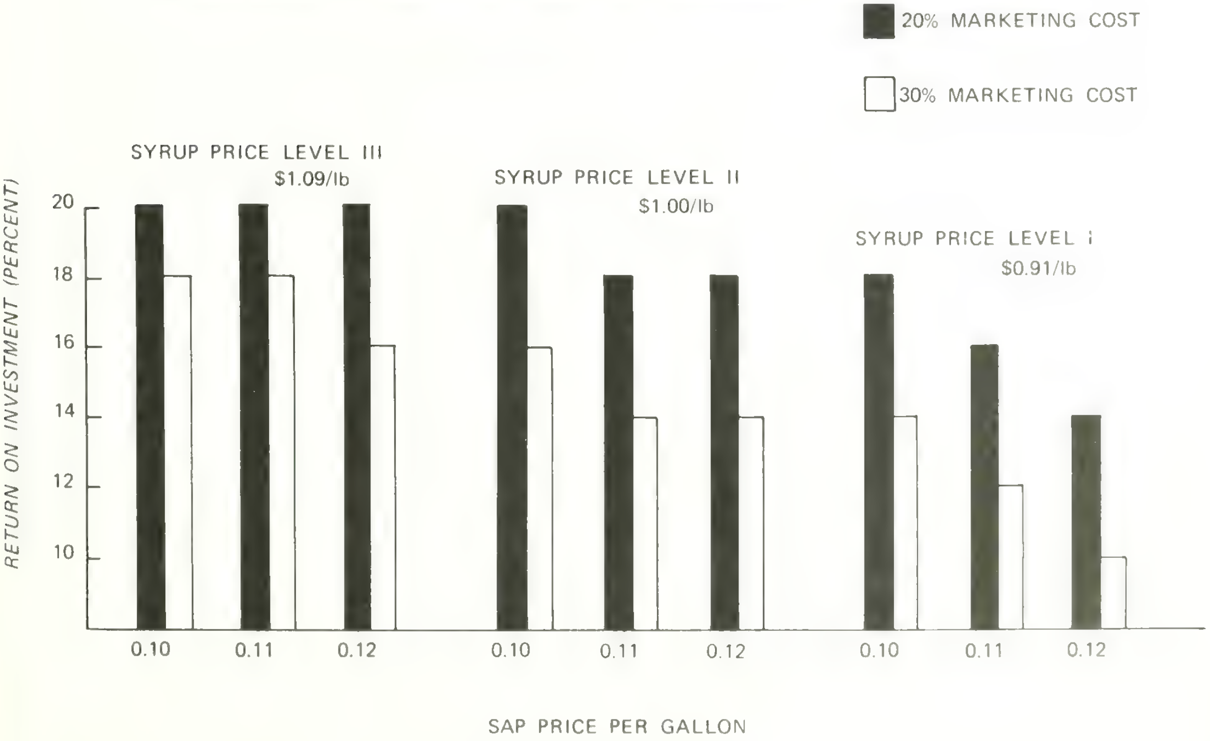


Figure 6.—Analysis of economic return on VCD plant investment at various levels of retail syrup price, sap price, and marketing cost.



required to evaporate 1 pound of water in an open-pan evaporator, only .047 pounds are required to evaporate 1 pound of water in a VCD plant.

- The estimated cost of processing 35 gallons of 2.5° Brix sap to 1 gallon of 66° Brix syrup in a VCD plant is $2.44, compared to $3.60 in a conventional plant. A VCD plant operating 35 percent below capacity produces syrup for $3.64 per gallon, approximately the same cost as a conventional plant.
- A VCD plant capable of processing 7,000 to 9,000 gallons of syrup during an 8-week season can realize a 10 to 18 percent return to the investor. The return and its associated risks must be weighed against those of other investments.

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Garrett, Lawrence D.
1977. **Processing maple syrup with a vapor compression distiller: an economic analysis.** Northeast. For. Exp. Stn., Upper Darby, Pa.
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ABSTRACT

In Detroit, Michigan, 12 plots, each containing about 600 American elm trees, *Ulmus americana* L., were subjected for 3 years to intensive and conventional sanitation treatments to control Dutch elm disease. In the intensive treatment, three disease surveys were conducted each year; each followed by tree removal within 20 working days. In the conventional treatment, one survey was conducted each year, and diseased trees were removed in late fall and winter. Results showed that the intensive sanitation treatment was significantly better than the conventional treatment each year. Arborists should consider the advantage of detecting and removing diseased elms promptly.

SINCE DUTCH ELM DISEASE, caused by the pathogen *Ceratocystis ulmi* (Buism.) C. Moreau, was first observed (in the Netherlands and later in the United States), sanitation has always been recommended as the major control procedure. Sanitation—the removal and disposal of diseased elm trees—not only reduces populations of both vectors, *Scolytus multistriatus* (Marsham) and *Hylurgopinus rufipes* (Eichhoff), the European and the native elm bark beetles respectively, but also the pathogen reservoir.

Miller et al. *(1969)* reported that when sanitation was used to limit the spread of Dutch elm disease where the European beetle was the primary vector, it was possible to hold elm losses to 2 percent or less per year. But when sanitation was discontinued, losses soared to an annual rate of 15 percent. In a sanitation study where the native beetle was the only known vector, Van Sickle and Sterner *(1976)* found that annual losses averaged 0.4 percent of the initial elm population. In both studies, sanitation was practiced from the onset of the disease.

In most large municipalities where there are heavy concentrations of elms, surveys for finding diseased elms are made in mid and late summer. Removal of these elms begins in the fall and often continues until late spring of the following year. This type of disease detection and tree removal is considered their conventional sanitation practice.

In my study, I wanted to use intensive sanitation: frequent surveys followed by removal of diseased trees within 20 working days after detection. I wanted to find what effect intensive sanitation would have on the disease incidence in a municipality where conventional sanitation was practiced, where the disease was well established, and where the European beetle was the primary vector.

Methods and Procedures

Tree and plot selection.—About 7,500 street-lawn American elms, *Ulmus americana* L., were selected from one contiguous area in Detroit, Michigan. The mean diameter at breast height was 22 inches (56 cm), and the mean height was 65 feet (20 m). Each spring, all trees were sprayed by mist blower with 12.5-percent methoxychlor emulsion at about 0.5 gallon (1.9 liter) per tree.

The area was divided into 12 plots, each having from 550 to 700 elm trees. Because the disease rate can be influenced by tree density, the plots were classified according to elm stocking: four plots had dense stocking, 2.7 to 3.1 stems per acre (0.4 ha); four had medium stocking 2.1 to 2.5 stems per acre; and four had sparse stocking 0.9 to 1.4 stems per acre. Six plots, two from each stocking, were selected randomly for a disease survey in June, July, and August of 1974, 1975, and 1976; each survey was followed by the prompt removal of diseased trees. The remaining six plots received the conventional sanitation treatment. The density strata of plots were considered in the selection process so that neither treatment would be applied to too many plots of similar elm density.

Disease surveys and tree removals.—During June, July, and August of each year, elm trees in the intensive sanitation plots were inspected for symptoms of Dutch elm disease. Trees in the conventional sanitation plots were inspected only during the August survey. The surveys were conducted by driving along each street twice, and visually examining trees to the right of the observer. Each diseased tree was tagged for removal and recorded. Diseased trees in the intensive sanitation plots were removed within 20 working days. Those in the conventional plots were removed during the fall and winter months. Trees removed for reasons other than Dutch elm disease were dropped from the study. The percentage of infected trees found each year in each plot was the incidence of the disease. The average of the incidence for all plots under each treatment was the average incidence.

Results and Discussion

Though the disease incidence fluctuated from one year to the next within and between sanitation treatments, consistently fewer elms were lost under the intensive treatment. By 1976, nearly twice as many elms were lost under the conventional treatment as under the intensive treatment (Table 1).

The average incidence of disease for both sanitation treatments for each year is shown in Figure 1. Data for each year were subjected to chi-square analysis. In 1974, intensive sanita-

Table 1.—Annual status of American elm trees treated by conventional and intensive sanitation, Detroit, Michigan, 1974-1976

Year	Conventional sanitation		Intensive sanitation	
	Number of trees	Number of diseased trees	Number of trees	Number of diseased trees
1974	3,585	226	3,856	198*
1975	3,347 [a]	214	3,642	141**
1976	3,132	400	3,489	212**

[a] Some trees were lost to other causes.
*Significant at 5 percent level.
**Significant at 0.1 percent level.

Figure 1.—Average incidence of Dutch elm disease in experimental plots, Detroit, Michigan, 1974-1976.

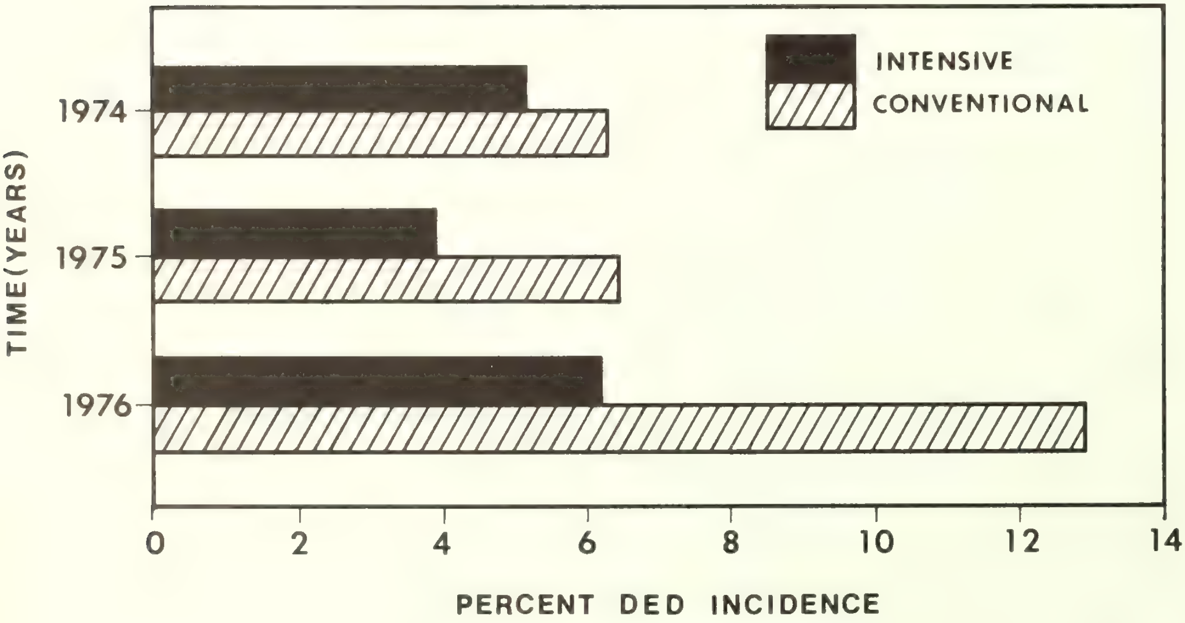
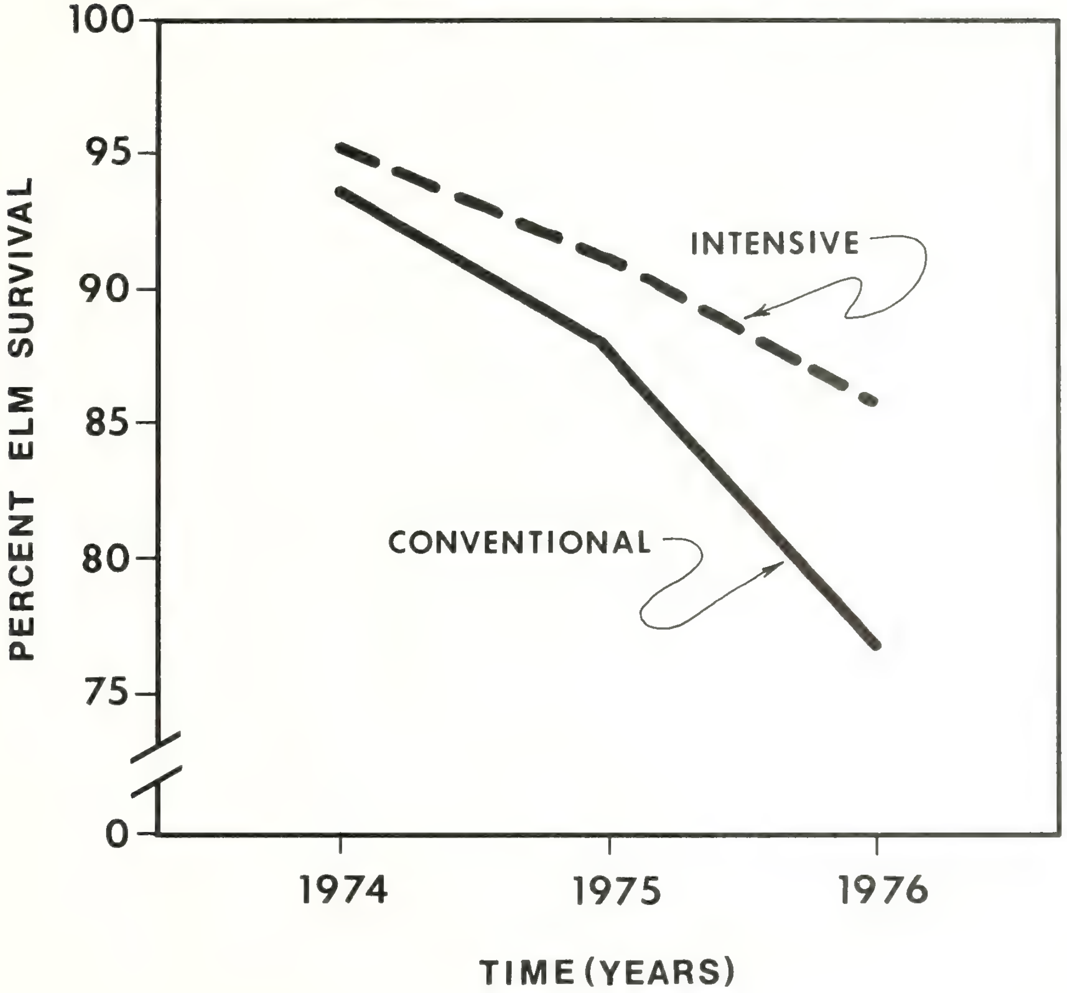


Figure 2.—Survival of American elms under intensive and conventional sanitation treatments. Percentage based on initial population, Detroit, Michigan, 1974-1976.



tion was significantly better than conventional sanitation at the 5 percent level ($X^2 = 4.7$, 1 df). And in 1975 and 1976, intensive sanitation was significantly better at the 0.1 percent level ($X^2 = 23.0$, 1 df; $X^2 = 88.2$, 1 df). The difference in the percentage of disease incidence between the intensive and conventional treatments increased each year. In 1974, the difference was only 1.17 percent, but it increased to 2.42 percent for 1975 and 6.69 percent for 1976.

Survival of elms under the intensive treatment was significantly superior to that under the conventional treatment over all 3 years (Fig. 2). The patterns of elm survival resulting from each treatment were compared in their entirety by a chi-square procedure proposed by Mantel *(1966)*. This analysis showed a highly significant difference between the survival-time patterns of the two treatments ($X^2 = 95.7$, $P < 0.001$).

Conclusions

The results of this study have clearly demonstrated the efficacy of frequent disease surveys followed by the prompt removal of diseased trees in limiting the spread of Dutch elm disease. In municipalities where conventional sanitation is now practiced, immediate consideration should be given to rescheduling survey and removal crews to detect and remove diseased trees promptly.

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Barger, Jack H.
1977. **Improved sanitation practice for control of Dutch elm disease.**
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4 p. (U.S. Dep. Agric., For. Serv. Res. Pap. NE-386)

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412:443.3--172.8 CER

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ABSTRACT

Recent research has shown that prompt removal of diseased elms reduces the incidence of Dutch elm disease more than the sanitation prac-[illegible] that allows diseased elms to remain standing into the dormant season. The key to prompt removal is repeated surveys to detect diseased elms as early as possible. Intensive sanitation can save more elms and cost less than the more conventional sanitation practice. A 3-year case history demonstrates savings of 25 percent in total cost and an additional 92 elms per thousand.

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DUTCH ELM DISEASE CONTROL:

INTENSIVE SANITATION AND SURVEY ECONOMICS

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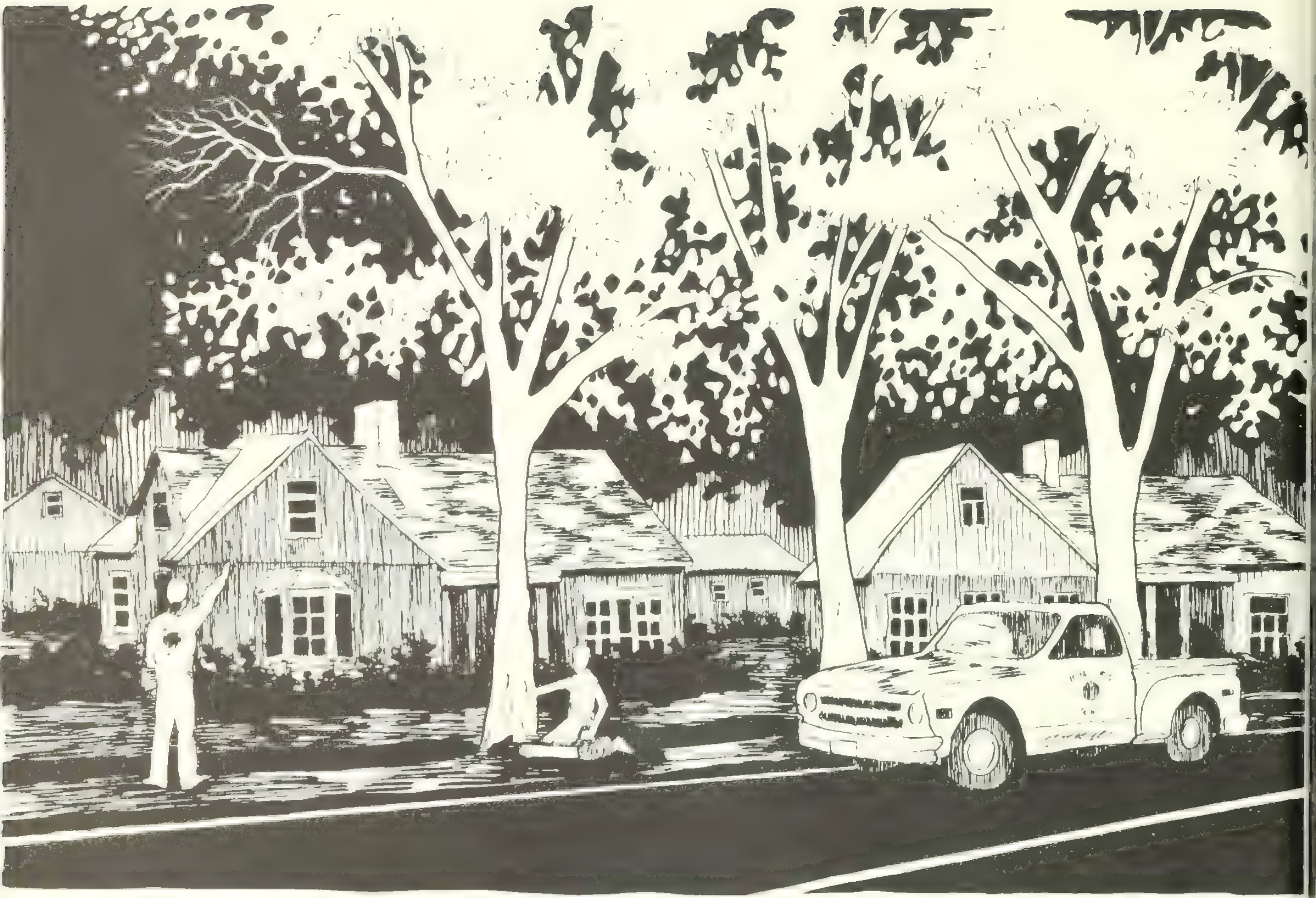

DO THE RIGHT THINGS AND DO THEM RIGHT

SANITATION, the removal and disposal of diseased elms and any elm wood that can be colonized by bark beetles, has long been the mainstay of successful Dutch elm disease control programs. Dead and dying elm wood serves as a reservoir for the disease fungus and the elm bark beetles that spread it. Eliminating this material reduces both the beetle population and the pathogen.

Prompt removal of diseased elms has been a recommended sanitation practice for many years (Whitten 1956; Neely 1961, 1975). Diseased trees found during the growing season (June 1 to August 1 in some areas) are removed within 30 days after the first symptoms were observed. Those found in late summer (after August 1) are removed during the dormant season so that by late spring (May 1) of the following year all diseased trees have been removed. Several communities have achieved good control by following this program (Marsden 1953, Miller and others 1969, Neely 1972, Van Sickle and Sterner 1976).

Many communities have Dutch elm disease control plans that call for such a sanitation program, but have found it difficult to carry out (Miller and others 1969). Their conventional sanitation program consists of a survey in mid- or late summer to detect diseased elms and removal of those trees during the fall and winter. Their goal is to have all the diseased trees removed before bark beetle emergence the following spring.

The early sanitation recommendations were intuitive, based on biological principles and some knowledge of the disease and its spread (Neely 1975). A recent study by Barger (1977) has shown that a more intensive sanitation program resulted in better control than the conventional sanitation practice. His intensive program consisted of frequent surveys and removal of diseased elms within 20 working days after symptoms were observed. All trees known to be diseased were removed before the dormant season, a departure from the previously recommmended sanitation practice.

Frequent surveys are the key to intensified sanitation. The success of such a program requires that diseased elms be detected and slated for removal as soon as the first symptoms are detected. This requires an efficient survey procedure.

Before organizing a new Dutch elm disease program or changing the emphasis of an ongoing one, a manager should consider the role that survey plays in the overall program. In this paper we present evidence of the cost of detection and its relation to the effectiveness of intensive sanitation. We have used a strictly financial approach to assess the impact of survey and tree-removal costs on the municipal budget. By focusing on sanitation as a control method we do not mean to imply that it is a cure-all for Dutch elm disease. It is the one measure however, that is basic to a great many successful control programs.

The Situation

In the community where we did this study (Detroit, Michigan), sanitation meant detecting diseased elms in one survey during the growing season and removing them during the dormant season. This community had lost 5 percent or more of its elms annually.

A large-scale pilot test involving 7,000 city-owned street-side elms was initiated in a section of this community in 1974 to find out whether a more intensive sanitation program would reduce the incidence of Dutch elm disease (Barger 1977). The study area was divided into 12 large adjoining blocks of about 600 trees each. All elms were sprayed with methoxychlor by mist blower in the spring of each year. Half of the blocks were selected at random to receive conventional sanitation, the remainder received intensive sanitation.

The intensive sanitation program consisted of surveys in mid-June, mid-July, and late August (the exact dates depended on local weather patterns). They were planned to locate elms that had been infected in the late fall of the previous year, or after the spring and summer beetle flights. Diseased elms were removed within 20 work days after the disease was detected. Survival of elms in each block was recorded in each of the 3 years of the experiment: 1974, 1975, and 1976.

The Survey Method

Three surveys were made each year in those blocks selected to receive intensive sanitation, each visually conducted by two experienced individuals. One drove a car slowly along the streets while the other paid strict attention to spotting Dutch elm disease symptoms. Only the street trees to the right of the observer were inspected, so each street was traversed twice to observe all elms. When a tree that showed disease symptoms was spotted, the car was stopped to make sure. If the diagnosis was confirmed visually, the tree was marked for removal.

Survey Analysis

Records of gross job time (Worley and others 1965) were kept for these surveys to see how expensive they were. The number of trees surveyed per hour and the number of diseased trees found was determined daily for each block. A total of 12 job times was evaluated for the initial survey, 9 for the second survey, and 8 for the third survey. The number of trees per mile of city street in each study area was determined from city maps and related to the survey times. These data were subjected to regression analyses.

Survey Performance

In the areas we surveyed, the number of elms per mile[1] along the streets varied from 24 to 80. The average distance between elms at the density of 24 per mile is 220 feet; at 80 per mile it is 66 feet. The cross streets had fewer elms than the main streets. At the lower densities the elms tended to be in clumps resulting from inroads of the disease, whereas at the higher densities they were more uniformly spaced.

We found that the first survey of the season took the most time. The disease rate ranged from 2 to 14 percent among study areas. However, the survey speed (trees/hour) was not directly related to the disease rate; it depended on the number of trees per mile surveyed (Fig. 1). As the number of trees per mile surveyed increased from 24 to 80, the number of trees surveyed per hour increased from 107 to 180.

Subsequent surveys in mid-July and late August were completed more quickly than the initial survey. Fewer elms were found to be diseased, the rate in the study areas ranging from zero to 2 percent. In these later surveys, the number of diseased elms observed was a factor in the time required. As in the initial survey, the number of trees per mile of street surveyed also affected the number of trees surveyed per hour. This relationship for disease rates of 0, 1 and 2 percent is illustrated in Figure 2. The regression lines are steeper, indicating that the later surveys were more sensitive to the number of trees per mile surveyed than the first survey of the season. The spacing between the regression lines in Figure 2 shows that for each percent increase in the disease rate up to 2 percent, about 73 fewer trees per hour were surveyed.

Survey Costs

The 1972 costs of the individual jobs included in the Dutch elm disease control programs of 39 municipalities were compiled by Cannon and Worley (1976). The costs of survey ranged from 15 to 30¢ per tree per year with the average being 20¢ per tree. We have brought these figures up to date, correcting for inflation during the 5-year period by using the wholesale price index; in terms of March 1977 dollars these costs would be from 24 to 48¢ per tree with an average of 32¢ per tree surveyed each year.

If we wanted to estimate the costs of the surveys made for the intensive sanitation program in our test community, we could use the cost data given above and the performance data from Figures 1 and 2. For example, the number of trees per mile of street in our test blocks averaged 57. Using the equation given in Figure 1, we find that in the initial survey of the season we could survey an average of 150 trees per hour. Multiplying 150 trees by the average cost of 32¢ per tree surveyed gives a product of $48 per hour.

The second survey of the season, made in mid-July, revealed that about 2 percent of the remaining elms showed symptoms of the disease. Using our average of 57 trees per mile (X_1) and a 2 percent disease rate (X_2) in the equation shown in Figure 2, we find that we could survey about 248 trees per hour. We assume that the hourly cost of this survey would not be any greater than that of the initial survey. Using the cost of $48 per hour, we find that the average cost of the second survey would be 20¢ per tree.

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[1] 1 mile = 1.609 kilometers, 1 foot = 30.48 centimeters.

Figure 1.—Trees surveyed per hour as a function of the number of trees per mile of city street surveyed—initial survey.

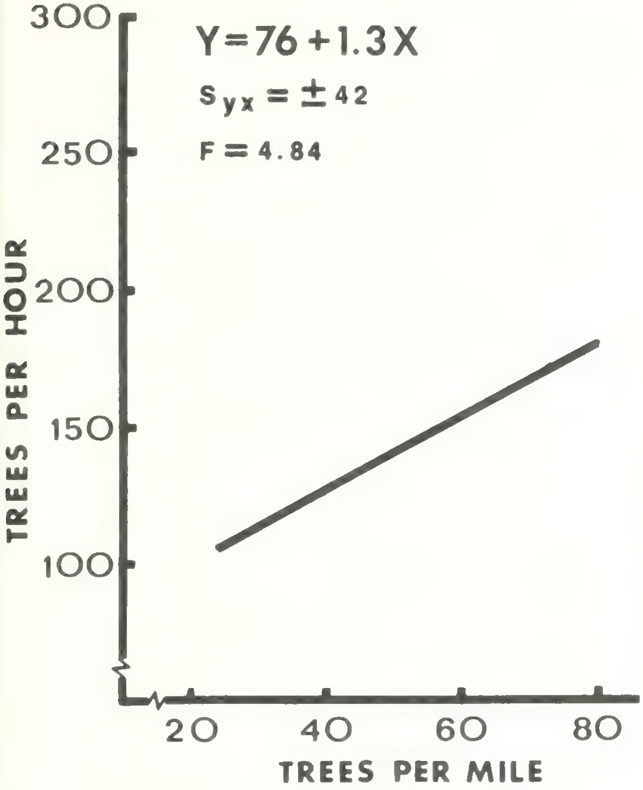
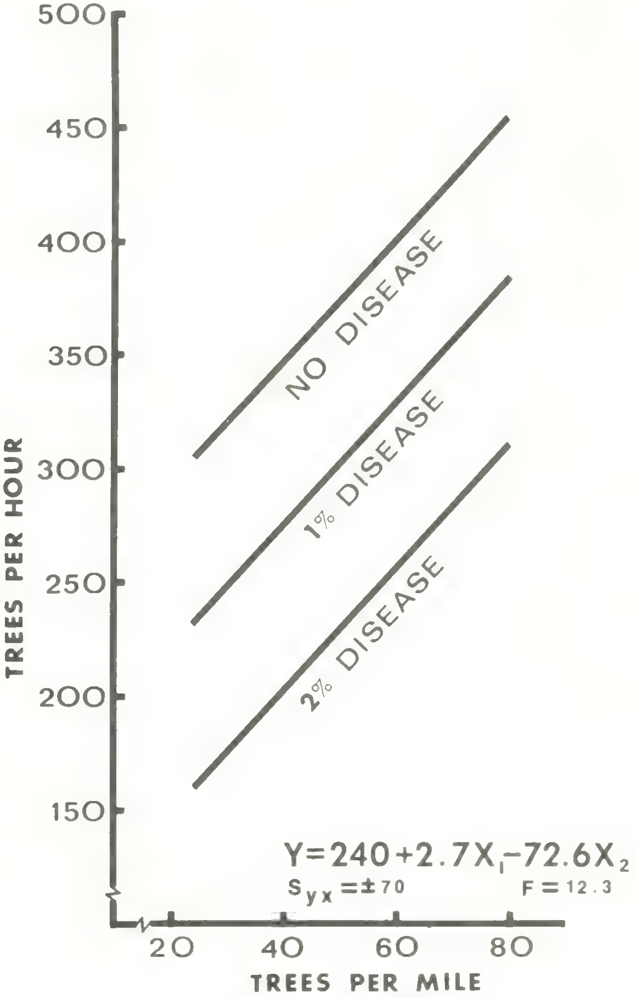


Figure 2.—Trees surveyed per hour for each of three disease rates, as a function of the number of trees per mile of city street surveyed—subsequent surveys.

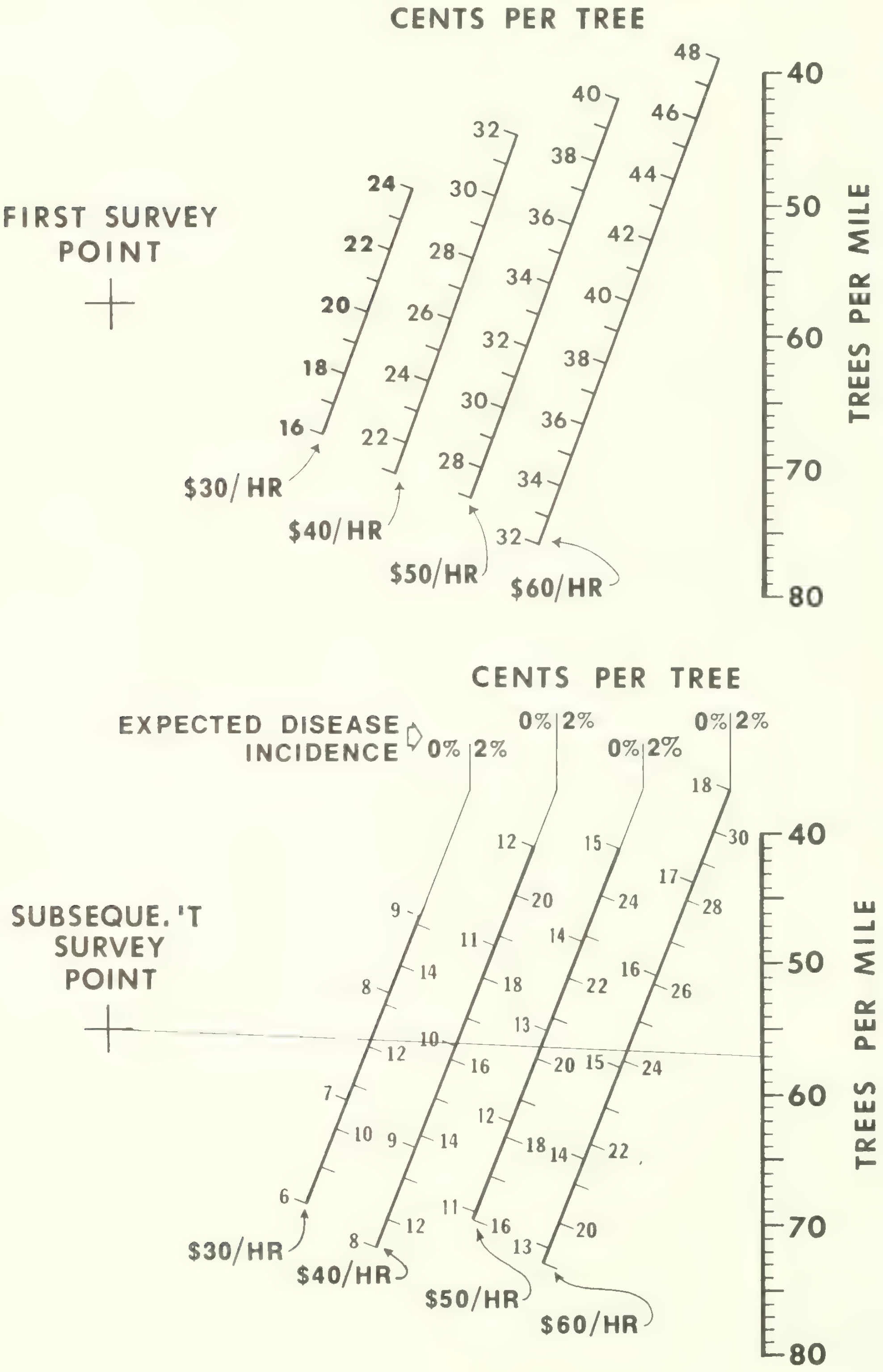


In the final survey, made in mid-August, we found that the average disease rate was about 0.6 percent. Repeating the procedure used for the second survey, we can show that the average cost of the third survey would be about 14¢ per tree.

How can this information be used for planning purposes? The costs we used in our example were determined by the average tree density in our test blocks and the average cost of survey from data of 39 municipalities. Obviously, meaningful cost information would have to be determined for each community using the tree density data, Dutch elm disease rate, and hourly cost data for that community.

To assist managers in estimating survey costs for their communities, we have prepared a nomogram (Fig. 3) from the information in Figures 1 and 2. For the initial survey of the season and subsequent surveys, the cost per tree can be found simply by placing a straight edge across the nomogram from the appropriate survey point to the appropriate point on the scale of trees per mile of street. The cost per tree appears under the line where it intersects the appropriate hourly cost scale. For the subsequent surveys, the cost per tree is shown for two levels of disease incidence. For example, using 57 trees per mile the line on the lower chart in Figure 3 intersects the 2 percent disease-incidence scale of the $50 per hour scaler at slightly above 20¢ per tree.

Figure 3.—Nomogram for determining the survey cost per tree. To use the nomogram: Draw a straight line between the appropriate survey point and the appropriate point on the number-of-trees-per-mile scale. The intersection of this line and the appropriate cost-per-hour scale gives the survey cost per tree.



Save-the-elms Evaluation

To justify the time and expense of additional surveys, an improvement in Dutch elm disease control must be shown. Evidence for such improvement was found by comparing the results of intensive sanitation with those of conventional sanitation (Barger 1977). Municipal disease-control performance described by Cannon and Worley (1976, Figs. 1 and 2) was used as a basis for evaluating this improvement (Figs. 4 and 5).

At the beginning of our study, the test community had a fair performance record, having held their losses to about 5 percent per year (Fig. 4). Using Barger's (1977) data, we plotted elm losses under both sanitation programs (Fig. 4). The intensive sanitation program was significantly better than the conventional method. Each year, under intensive sanitation, fewer elms were lost to the disease than in the areas where conventional sanitation was used.

The results of our two sanitation programs were superimposed on the records in Figure 5 that show the length of time in which save-the-elms goals can be achieved with different program performance levels. The superiority of intensive sanitation over the conventional practice is clear. The effect of intensive sanitation may be to begin to move from fair performance toward good performance.

Survey is the key to removing diseased elms and, as the evidence presented in Figures 4 and 5 shows, multiple surveys and prompt removal lead to lower incidence of Dutch elm disease.

Figure 4.—Number of trees expected to die each year under each of four control-program performance levels. Enlarged section illustrates the results of conventional and intensive sanitation programs superimposed on these performance levels.

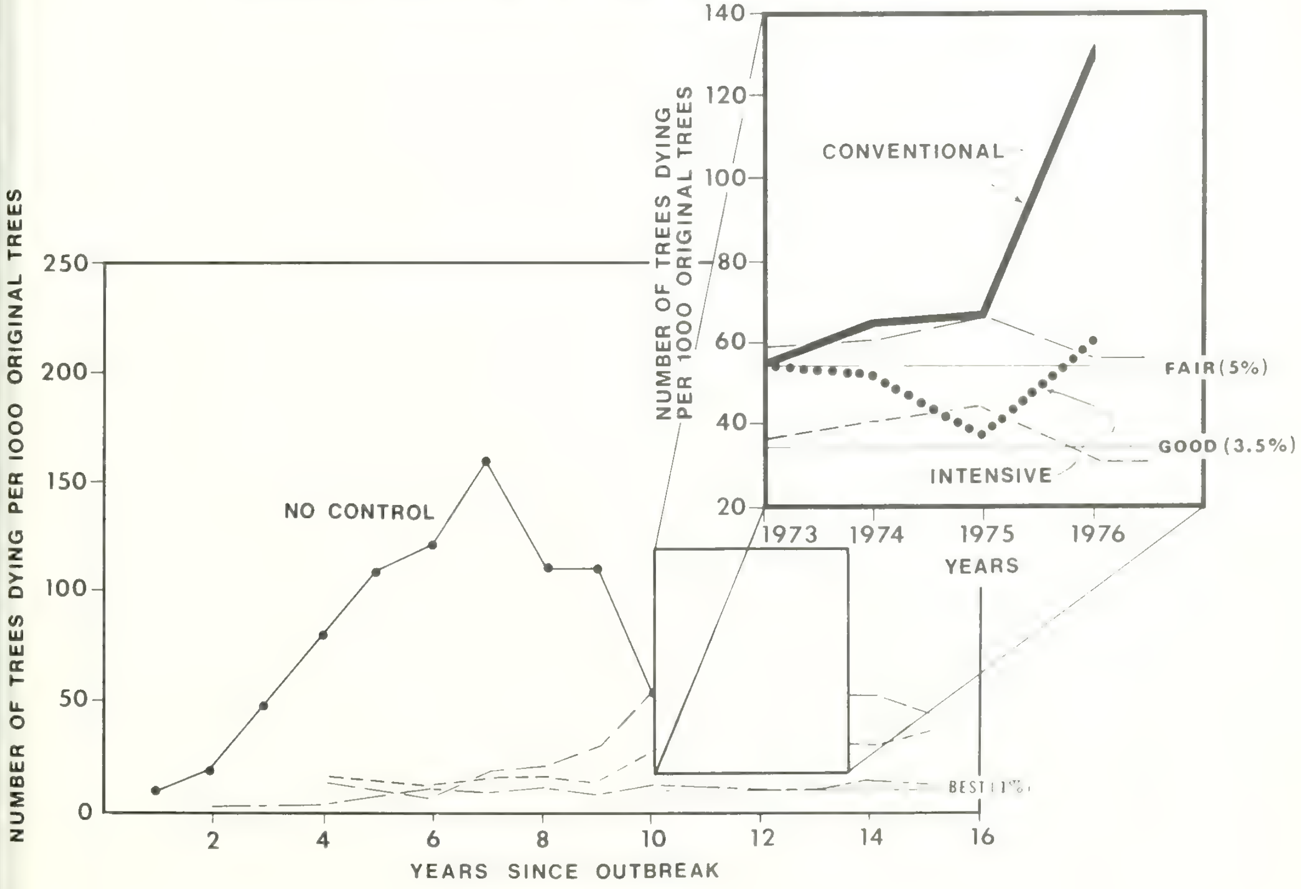
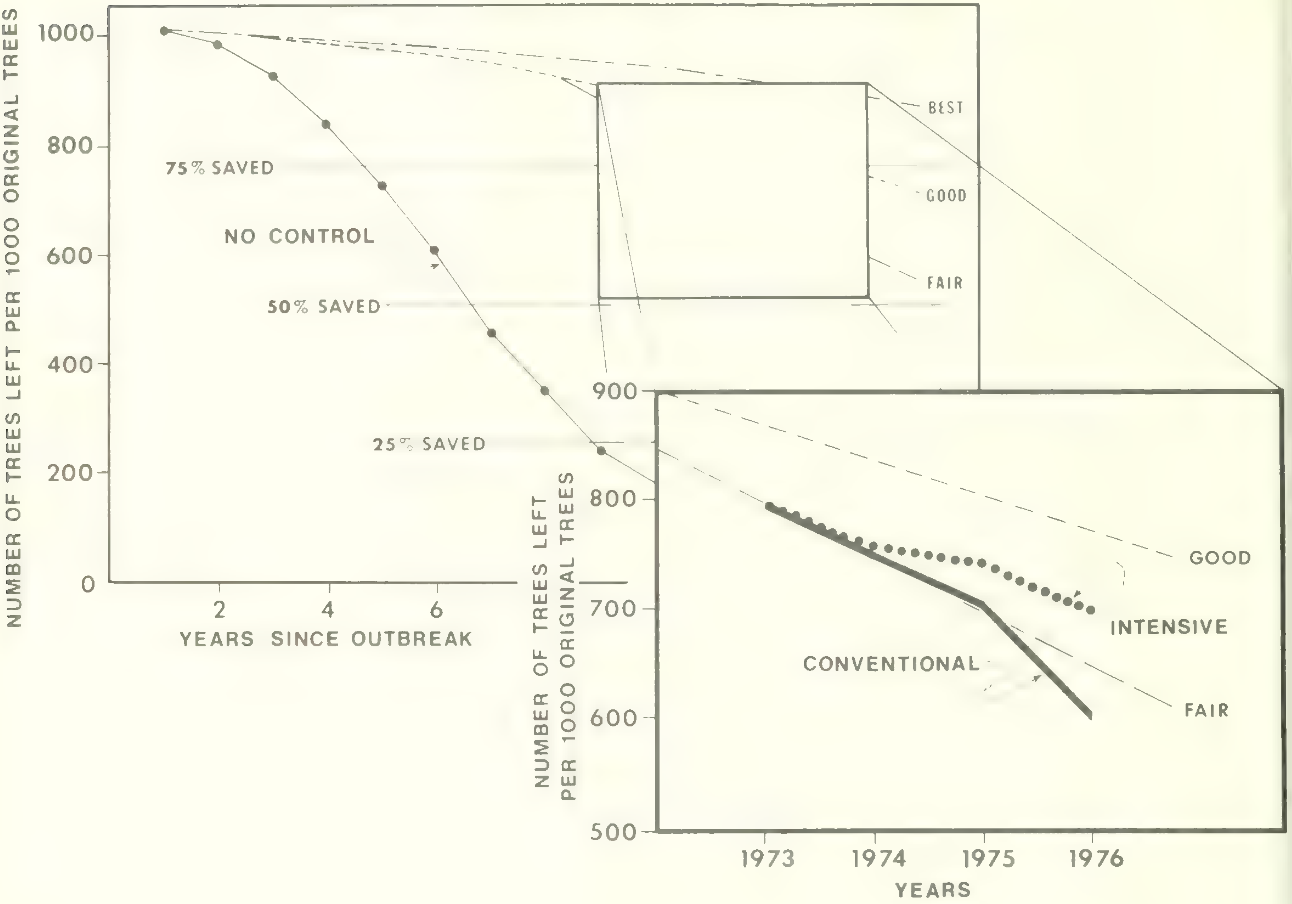


Figure 5.—Length of time in which save-the-elms goals can be achieved with different control-program performance levels. Enlarged section illustrates the results of conventional and intensive sanitation programs in terms of elms saved.



Financial Consequences

An example of how the costs of an intensive sanitation program might compare with those of a conventional program is given in Table 1. Our 3-year case history is presented to illustrate the budget for each sanitation program. We used the survey performance and costs developed earlier in this paper and the average tree-removal costs updated from the Cannon and Worley (1976) report. Tree-removal costs were increased by 20 percent for the intensive program, because crews must return again and again to the same areas to remove diseased trees.

After 3 years, the total cost of surveys for the intensive sanitation program was almost twice the survey cost for conventional sanitation. The tree removal costs, however, were less than 3/4 of those in the conventional program. This reduction in tree-removal costs far outweighed the increase in survey cost. The total amount saved by following the intensive program was 25 percent of the cost of the conventional program.

Comparison of the yearly costs revealed a small dollar saving for the first year. This saving grew rapidly until, by the end of the third year, the cost of intensive sanitation was only 60 percent of the cost of conventional sanitation.

Table 1.—Economic comparison of intensive versus conventional sanitation, based on a 3-year study, by 1,000-tree units

Item	Elms[a]		Dollar cost[b]			Dollar savings	Percent savings
	Beginning of season	Diseased removed	Survey	Removal	Total		
Intensive sanitation[c]							
Year 1	1,000	51	599	12,291	12,890	93	1
2	949	37	571	8,917	9,488	2,872	23
3	912	55	544	13,255	13,799	8,994	39
Total		143	1,714	34,463	36,177	11,959	25
Conventional sanitation[d]							
Year 1	1,000	63	320	12,663	12,983		
2	937	60	300	12,060	12,360		
3	877	112	281	22,512	22,793		
Total		235	901	47,235	48,136		

[a] Elm loss data from Barger (1977).

[b] Based on March 1977 dollars.

[c] Surveys made in mid-June, when 61% of the total diseased elms were identified; mid-July, 32%; late August, 7%. Survey cost set at $40 per hour. First survey at 32¢ per tree, subsequent two surveys at 1% disease rate at 14.5¢ per tree each survey. Cost of intensive tree removal set at $241 (cost of conventional removal plus 20% for extra effort required).

[d] Costs based on data from Cannon and Worley (1976); one survey at 32¢ per tree, and conventional removal during dormant season at $201 per tree.

Even More Surveys?

Our 3-year case history shows savings of both elms and money from following an intensive sanitation program. It may be possible to reduce the incidence of Dutch elm disease even further by increasing the number of surveys made during each season, provided that each survey is followed by prompt removal of diseased elms.

If the number of surveys per season were increased from three to four, if more diseased elms were found, and if prompt removal of these elms reduced the incidence of Dutch elm disease and thus the total cost of removing diseased trees, then the additional survey would have paid off. On the other hand, if four surveys during the summer revealed no more diseased elms than three surveys, then the fourth survey would contribute nothing. Since the cost of removing diseased elms now averages about $240 each in the intensive sanitation program, the cost of an additional survey might be justified if only one more elm per thousand were saved.

What would the picture be if we could lower the incidence of Dutch elm disease by adding another survey to our intensive sanitation program? We selected the most severe set of circumstances from our data: a sparse elm population (24 trees/mile) with 2 percent diseased so that the survey would proceed at a rate of about 160 trees per hour.

A scenario based on the above circumstances, patterned after the 3-year case history of intensive sanitation (Table 1), showed that if two additional trees per thousand could be saved each year, then an additional saving of 2 percent could be achieved. These savings would rise to 6 percent if four additional trees per thousand per year could be saved. The method for deciding whether another survey is warranted is presented in the Appendix.

Summary and Discussion

Surveys to detect Dutch elm disease are basic to any type of control program: early detection of the disease is essential to its effective control. When early detection was coupled with prompt removal of diseased elms, as in Barger's (1977) intensive sanitation program, then significant improvement in control was achieved.

A control effort that can reduce the number of trees that have to be removed without costing more than removing those trees will fit into a municipal budget without requiring additional annual funds. In our case the improved control program saved money as well as elms. This reinforces our view that frequent and thorough surveys are a worthwhile investment.

At present, diseased elms in most communities are detected by ground survey. Crews rely on visual identification of foliar symptoms of the disease. Although this method has been considered expensive in time, personnel, and transportation, our results show that it is well worth the cost.

We have used a fiscal perspective in this paper to assess the impact of survey and tree-removal costs on the municipal budget. It is important to note that by taking this viewpoint we have left out significant portions of the Dutch elm disease picture. We have not discussed the value of elm trees alive and well in city neighborhoods—a value that greatly overshadows the costs of surveys and tree removal. From the broader point of view of the total community, the physical, biological, and social benefits of saving trees are much greater than the monetary savings we have indicated.

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Appendix

How to Decide About Another Survey

The point at which the cost of added surveys balances the cost of removing trees depends on the number of trees that could be saved by the additional surveys. The break-even point for a 1,000-tree unit is easily computed, given the operating cost per hour and the number of hours required to survey 1,000 trees, or the survey cost per tree (determined from the nomogram in Fig. 4). Thus, since the

cost of another survey = *(survey cost per tree* x *1,000)*

or

= *(cost per hour)* x *(hours to survey 1,000 trees),*

then the

$$\textit{(number of trees per 1,000 that have to be saved to break even)} = \frac{\textit{cost of another survey}}{\textit{cost of removing one tree.}}$$

For example, using our data for the highest-cost late-season survey, we find the

survey cost per tree = 30¢
survey cost per hour = $48
hours to survey 1,000 trees = 6.25

so that the *cost of another survey* = (30¢ per tree) x 1,000 = $300

or

($48 per hour) x (6.25 hours per 1,000 trees) = $300

Then dividing the *cost of another survey* by the *cost of removing one tree,* we find that

$$\frac{\text{\$300 survey cost}}{\text{\$240 to remove one tree}} = \text{1.25 trees need to be saved per 1,000 trees to break even.}$$

If you expect that an added survey and prompt removal will save 1.25 or more trees per thousand, then do the survey.

Suppose there are fewer than a thousand trees in a unit, say 800; 800 = 0.8 thousand trees and you need to save at least 0.8 x 1.25 = 1 tree to break even on the added survey. On the other hand, if you have 3,200 elm trees (3.2 thousands), then you need to save 3.2 x 1.25 = 4 trees or more to justify the expense of the added survey. If more trees than these could be saved, so much the better.

Actually, in choosing between three or four or more surveys a year as part of an intensive sanitation program, it is not necessary to save the "break even" number of trees each and every year; you only have to save that number on the average. If the number of trees that you could expect to save in an ordinary year was marginal, than an additional survey may be thought of as insurance policy against the exceptional year.

Headquarters of the Northeastern Forest Experiment Station are in Upper Darby, Pa. Field laboratories and research units are maintained at:

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- Warren, Pennsylvania.

Cannon, William N., Jr., Jack H. Barger, and David P. Worley. 1977. **Dutch elm disease control: intensive sanitation and survey economics.** Northeast. For. Exp. Stn., Upper Darby, Pa. 19 p., illus. (U.S. Dep. of Agric. For. Serv. Res. Pap. NE-3[illegible])

Recent research has shown that prompt removal of diseased elms reduces the incidence of Dutch elm disease more than the sanitation practice that allows diseased elms to remain standing into the dormant season. The key to prompt removal is repeated surveys to detect diseased elms as early as possible. Intensive sanitation can save more trees and cost less than [illegible] sanitation practices. A 3-year cumulative demonstration [illegible] percent fewer [illegible] and an additional [illegible] per thousand.

Keywords: [illegible]

[illegible]

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INCREASING THE EFFICIENCY OF MAPLE SAP EVAPORATORS WITH HEAT EXCHANGERS

by Lawrence D. Garrett, Howard Duchacek, Mariafranca Morselli, Frederick M. Laing, Neil K. Huyler, and James W. Marvin

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ABSTRACT

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The Authors

A study of the engineering and economic effects of heat exchangers in conventional maple syrup evaporators indicated that: (1) Efficiency was increased by 15 to 17 percent with heat exchangers; (2) Syrup produced in evaporators with heat exchangers was similar to syrup produced in conventional systems in flavor and in chemical and physical composition; and (3) Heat exchangers reduce per unit production costs, and can yield greater production and higher profits.

INTRODUCTION

TRADITIONALLY, thermal evaporation techniques have been used in producing maple syrup. In fact, the basic principle has changed little in 200 years. Indians made incisions along the trunks of maple trees, and caught sap in bark or clay receptacles. They put the sap in a hollow tree trunk, and boiled it by dropping heated stones into the sap. The early colonists substituted a wooden spout for the reed or bark spout, and iron or copper kettles for tree trunks. Boiling the sap outdoors gave way to boiling indoors, usually in the woodshed. Kettles were later placed on arches, and iron pans were substituted for the kettles (Nearing and Nearing 1950); eventually the iron pan gave way to today's evaporator.

Modern evaporators are heated by fuel oil, solid round or split wood, or natural or propane gas; these systems differ only in the design of the firebox and the pan (Willits 1965).

The choice of fuel depends on the availability, price, and effect of the fuel on the efficiency of an evaporator. Oil has been used by most of the larger operators, but the current energy crisis has severely affected its availability and price.

Solid wood has been used by small operators because of its availability at a lower cost on the farm. However more labor is required for firing, and the moisture content of wood varies; so wood is not always as efficient as oil or gas.

The least used fuel, gas offers the greatest efficiency in pounds of steam produced per unit of heat. Gas is used mostly for firing syrup finishing pans, but its high price and limited availability in maple producing regions have minimized its use.

There have been other attempts to increase the efficiency of the evaporator system. The most accepted modification is the evaporator hood. The hood prevents steam from building up in the sugarhouse, and foreign material from entering sap and syrup pans. The use of oil fuel guns, gas pressure nozzles, and improved insulating materials has also helped increase efficiency.

An innovation that increases the efficiency of conventional evaporators significantly is the heat exchanger. The exchanger uses steam that would have been lost in the evaporation process to preheat incoming sap. This energy can raise the temperature of cold sap (40°F) in the tube bundle to about 190°F. Previous attempts to preheat sap with heat exchangers have been ineffective because these exchangers were poorly designed.

Raithby (1974) developed a well-designed heat exchanger that incorporated the tube bundle into a hood. A drip pan was added so that water that condensed on the tubes would not drip back into the sap pan. In Raithby's tests with an oil-fired evaporator, efficiency was increased by 15 percent.

The purpose of this study was to:

- Analyze the energy loss in a conventional open-pan evaporator heated by fuel oil.
- Demonstrate how a preheater affects this energy loss in increasing operating efficiency.
- Evaluate the effect of a heat exchanger on the quality of the product.
- Develop and test a prototype exchanger that can be readily built by a manufacturer or producer.
- Analyze the heat exchanger as a capital investment.

METHODS

Test Evaporators

Two identical Grimm[1] evaporators systems were compared in a laboratory to determine the increase in efficiency after a heat exchanger

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[1] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

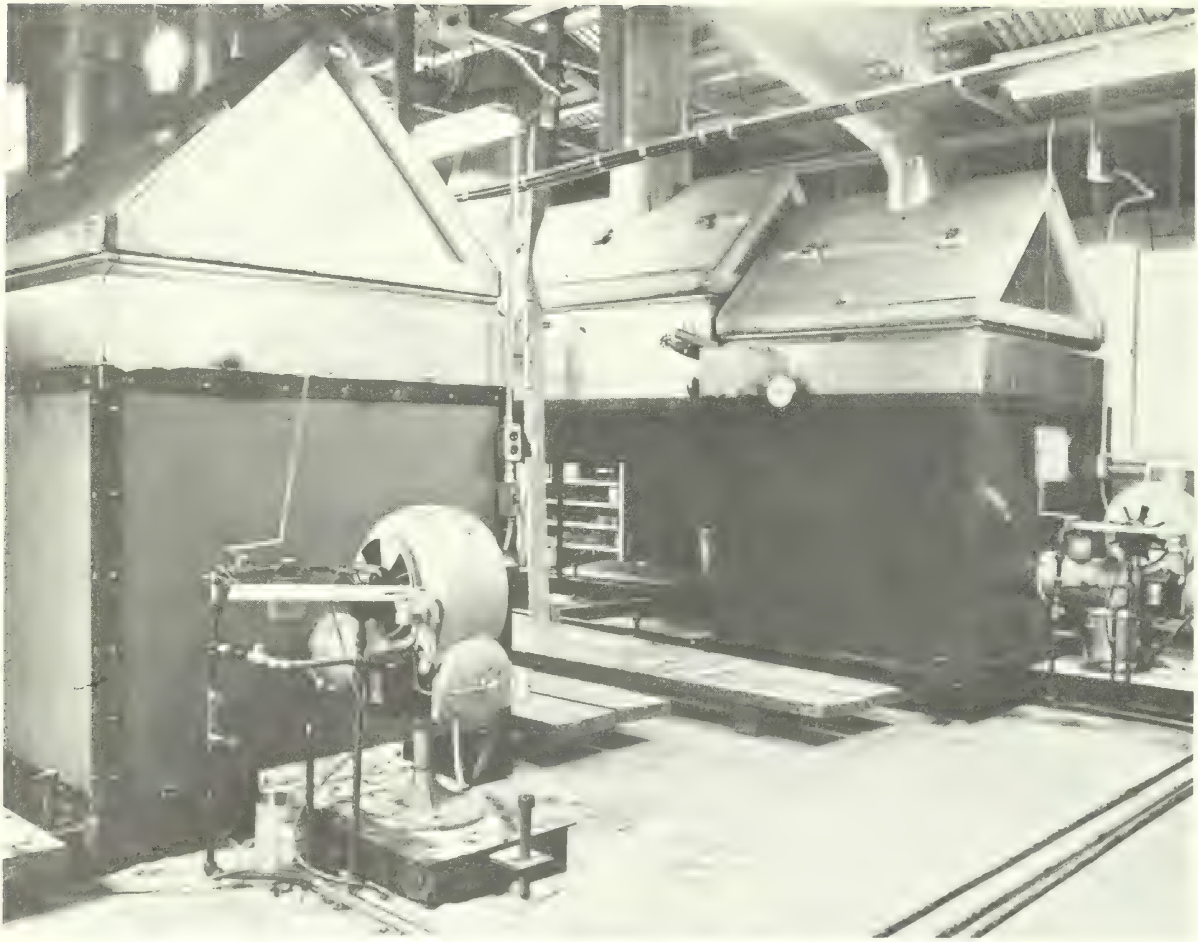


Figure 1.—Identical 4- by 10-foot Grimm evaporators used in lab tests to determine efficiency with and without a heat exchanger.

(series flow) had been installed on one of the units (Fig. 1). These results were verified by comparing the efficiency of a Lightning evaporator—with and without a heat exchanger (parallel flow prototype)—during an actual operation.

The two 4- by 10-foot oil fired, open-pan Grimm evaporators were original factory equipment, and were installed to manufacturer's specifications. These evaporators were fully insulated, and were fired by identical oil burners; each oil burner was equipped with two 5-gallon-per-hour nozzles. Each evaporator was factory rated at 175 gallons of 2.5° Brix sap per hour; the manufacturer's energy efficiency rating for each unit was 75 percent.

The 6- by 19-foot Lightning evaporator was 10 years old and was in an average state of repair; insulation was poor to average. This evaporator was fired by four oil burners, two under the front or syrup pan, and two under the back or sap pan. A total of 31 gallons of fuel was fired per hour.

Experimental Heat Exchangers

The initial series flow heat exchanger that we designed was encased in a hood, and was installed over the 4- by 6-foot sap pan on one of the Grimm evaporators (Fig. 2). A total of 36 feet of 1-inch copper tubing, connected in series, comprised the tube bundle. The hood was a 1/16-inch aluminum sheet, and was constructed so that it was as air-tight as possible. A drip pan and transfer tube were used to collect water that condensed on the tube bundle.

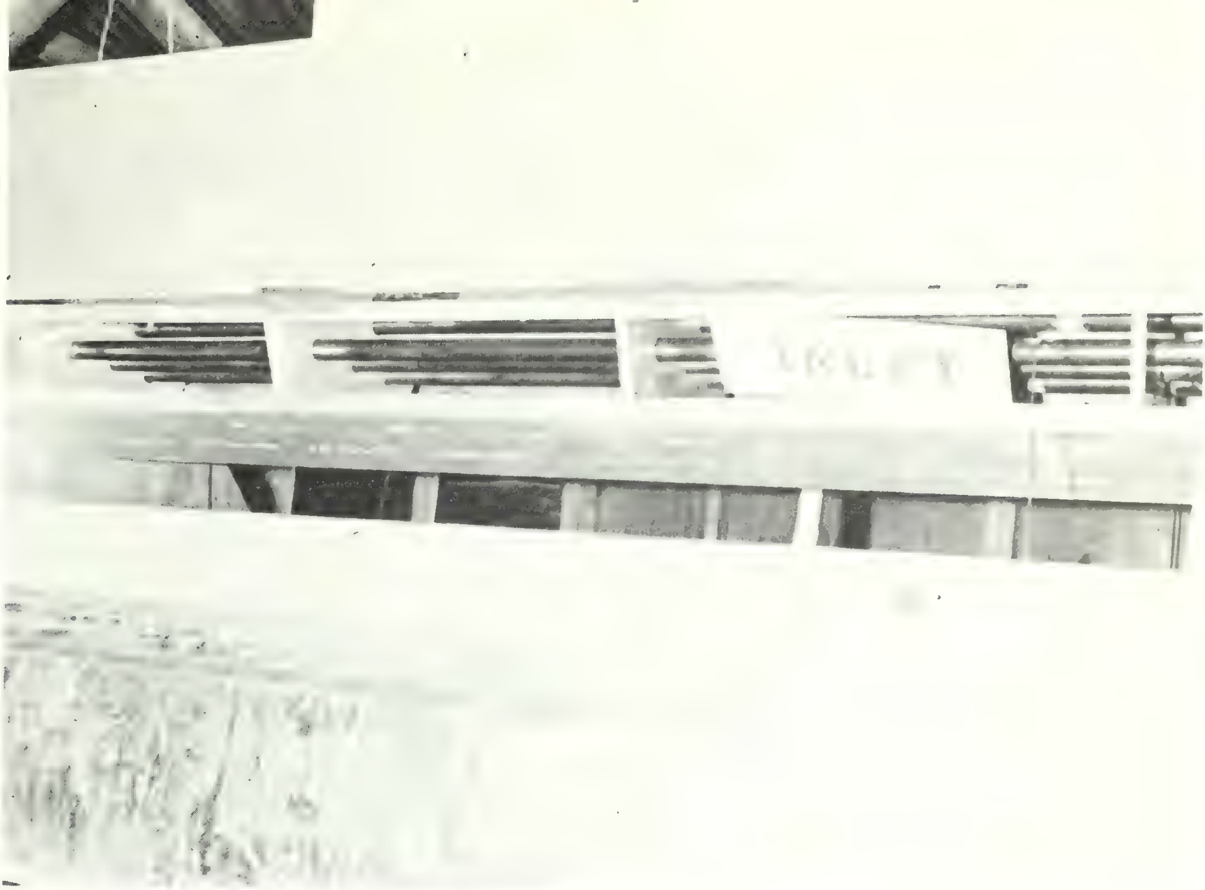
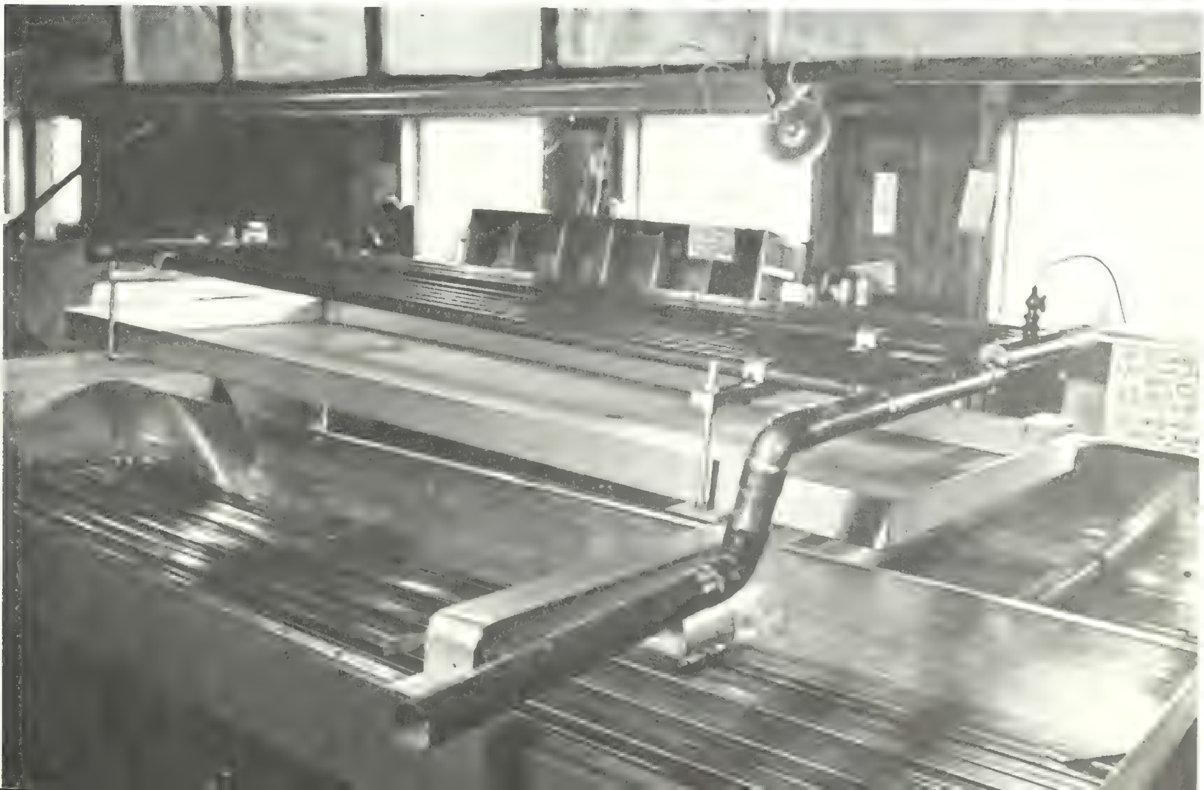


Figure 2.—Series flow heat exchanger designed for a 4- by 6-foot flue pan.

Figure 3.—Experimental parallel flow heat exchanger designed for a 4- by 6-foot flue pan.



This original series flow exchanger passed through three design stages to a final parallel flow prototype (Fig. 3). The parallel flow exchanger included two 1-1/4-inch diameter headers connected by twelve 3/4-inch copper tubes; the parallel flow prototype had a wider drip pan than the series flow exchanger.

Determining Evaporator Efficiency

The efficiency of an open-pan evaporator is determined by:

1. Calculating the pounds of water evaporated per pound of fuel consumed, or;
2. Computing the energy loss from the system.

The first procedure establishes a thermal efficiency ratio; the latter identifies the factors that reduce operating efficiency.

Thermal efficiency ratio.—Three values are needed to calculate the thermal efficiency ratio:

1. Btu in water evaporated: Pounds of water evaporated per hour times Btu required to vaporize each pound (1042.3); plus pounds of sap heated per hour times the difference between the sap temperature and 212°F; times Btu required to raise 1 pound of water 1°F (970.3).
2. Btu in syrup produced: Pounds of syrup per hour times Btu transferred to each pound.
3. Btu in fuel: Btu per pound of fuel times the number of pounds used per hour.

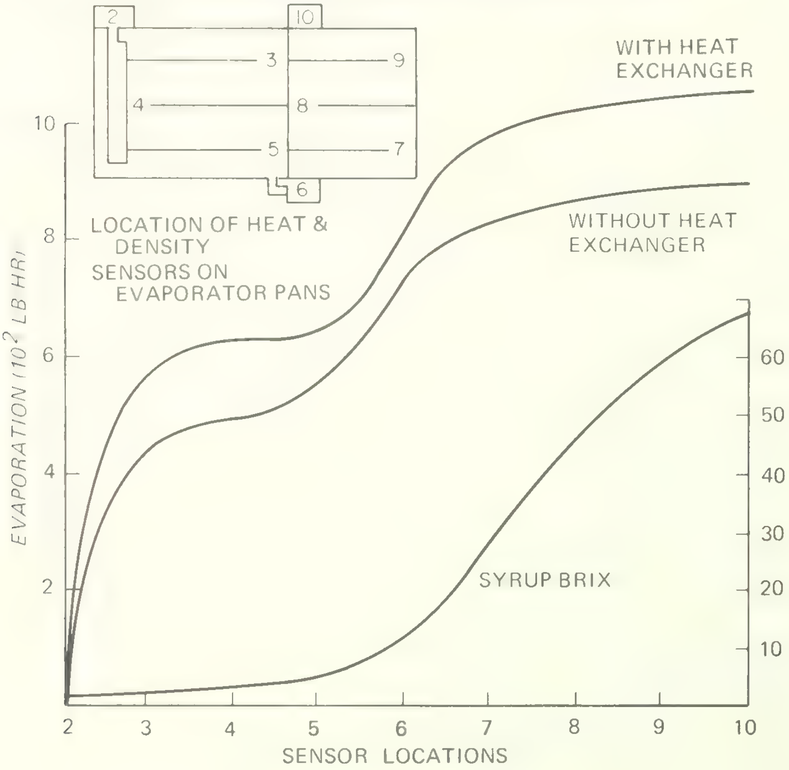
Energy loss.—The thermal energy loss from the evaporator system includes loss to stack gas; loss to incomplete combustion; loss to water formed by combustion of hydrogen in the fuel and oxygen in the air; and loss through the arch by convection and radiation.

These losses are usually expressed as a percentage of energy originating from the fuel; the efficiency of the evaporator is determined by subtracting this percentage from 100.

Location of Heat Exchanger

The steam released above the sap and syrup pans affords the greatest opportunity for increasing the efficiency of an evaporator. To

Figure 4.—Total accumulative evaporation and syrup Brix level at different locations in evaporator pan.



determine the best location for an exchanger, we measured the heat distribution (sap temperature and percentage of dissolved solids) at nine locations in the sap and syrup pans. Data indicated that the greatest amount of evaporation and heat transfer (45 to 50 percent) occur from the sap inlet to the center of the sap pan (Fig. 4); so this area above the sap pan was the best location for an exchanger.

There is relatively little heat transfer (7 to 10 percent) between the center of the sap pan and the sap pan outlet; an additional 25 to 30 percent of evaporation and heat transfer occurs between the syrup inlet and the center of the syrup pan. Seven to 10 percent occurs from the center of the syrup pan to the syrup pan outlet.

RESULTS

Evaporator Efficiency Without Heat Exchanger

Thermal efficiency ratio.—The Grimm evaporators (each without a heat exchanger) consumed an average of 71.16 pounds of fuel (8.9 gallons) per hour, and produced an average of 1029.9 pounds of evaporated water and 37.03 pounds of syrup. The Btu equivalent of the water evaporated and syrup produced was 1,031,500, while the Btu equivalent of the fuel used was much larger, 1,394,000. The ratio $\frac{1.032}{1.394}$ equals .74; that is, 74 percent of the fuel energy was transferred directly to steam product. The efficiency ratio of the evaporator is: 1.35 pounds of steam produces 1 pound of water, $\frac{1}{.74} = 1.35$.

Energy loss.—Five 3-hour tests (Table 1) indicated that losses of energy in both evaporators (without heat exchangers) averaged about 26 percent. The major loss of energy was to stack gas, 16.6 percent. Loss of energy to formation of water in the combustion process was 7.3 percent, and loss through the arch was 2.3 percent. A small loss, 0.19 percent, was due to incomplete combustion.

Efficiency With Heat Exchanger

Series flow.—In eight 3-hour tests, the efficiency of the Grimm evaporator with a series flow heat exchanger averaged 83.5 percent (Table 2); the efficiency of the evaporator without an exchanger averaged 72.9 percent. Four tests were run on each unit; 10 gallons of No. 2 fuel oil were fired per hour, with a higher heating value of 19,585 Btu per pound. The higher heating value is the expected yield of Btu per pound of fuel for a particular type of fuel and evaporator system.

The average increase in evaporated water due to the heat exchanger was 14 to 15 percent; the average increase in syrup production was 16.7 percent. An increase in syrup production is not an accurate measure of efficiency because it varies with the sugar content of sap.

We encountered problems in testing the series flow unit; repeated surging in the tube bundle indicated that air was trapped in the bundle, causing air locks and restricing flow. So it was necessary to increase the "head", or the vertical distance between the sap tank and the regulator box.

Parallel flow.—Four 10-hour tests of the

Table 1.—Energy loss and efficiency for two 4- by 10-foot oil-fired maple syrup evaporators (in percent)

Energy lost to:	Test					Average
	1	2	3	4	5	
Stack gas	15.10	14.80	17.30	16.90	19.20	16.66
Hydrogen combustion	7.60	7.20	7.10	7.50	7.30	7.34
Incomplete combustion	.14	.16	.20	.30	.18	.19
Arch	2.30	2.30	2.30	2.30	2.32	2.30
Total	25.14	24.46	26.90	27.00	29.00	26.49
Efficiency	74.86	75.54	73.10	73.00	71.00	73.51

Table 2.—*Effect of series flow heat exchanger on syrup production and efficiency of 4- by 10-foot oil-fired maple syrup evaporator*[a]

Test	Syrup production		Efficiency	
	Without exchanger	With exchanger	Without exchanger	With exchanger
	lb./h		*Percent*	
1	31.2	36.6	72.9	82.0
2	33.7	37.0	71.0	84.5
3	33.6	40.2	74.4	79.9
4	33.3	39.8	72.2	87.8
Average	32.9	38.4	72.9	83.5

[a] 10 gallons of oil fired per hour.

Table 3.—*Efficiency analysis of parallel flow heat exchanger on a commercial maple syrup evaporator*

Item	Without exchanger	With exchanger (tubing length)		
		76.8 feet	134.4 feet	190.0 feet
Sap				
Sugar content (°Brix)	2.58	3.32	3.36	3.09
Temperature				
Cold (°F)	43.50	32.70	36.20	38.20
Hot (°F)	—	163.50	194.40	205.80
Flow (gal/h)	286.41	346.32	350.46	355.83
Syrup produced (gal/h)	8.79	12.77	14.49	11.56
Water evaporated (lb/h)	2,320	2,686	2,713	2,752
Distillate (lb/h)	—	357.44	439.82	504.79
Oil (lb/h)	221.19[a]	222.49[b]	222.49[b]	222.49[b]
Average efficiency (%)	61.21	71.39	71.93	72.75
Average increase (%)	—	16.49	17.37	18.72

[a] 19,551 Btu/lb.
[b] 19,519 Btu/lb.

Lightning evaporator, with and without a parallel flow heat exchanger, indicated that efficiency with the exchanger increased by an average of 17.52 percent (Table 3).

The parallel flow exchanger seemed to offer solutions to:

- Tubing size: The manifold design should allow manufacturers to increase the tube surface by adding more tubes of the same diameter. This can result in cost savings to the manufacturer and the producer; the problem of changing design specifications for different evaporators is minimized.
- Head requirements: Because of the manifold design, there is less flow restriction and, therefore, less head requirement. A producer who uses a series flow design may be forced to use larger tubing or elevate the sap tank, or both.
- Hoods: Alteration of the low profile steam hood is not required with a parallel flow exchanger.

Vapor locking can be prevented in both the series flow and parallel flow systems if a suitable vapor vent is used.

Testing the Parallel Flow Heat Exchanger

The prototype parallel flow heat exchanger was designed so that we could simulate an undersized unit, a properly sized unit, and an oversized unit. Only 76.8 feet of tubing was used for the undersized unit; tubing length was increased to 134.4 feet and 190.0 feet for the properly sized and oversized units, respectively. Increasing the amount of tubing by 250 percent (76.8 feet to 190.0 feet) increased efficiency only by 1.36 percent (Table 3); beyond a given point, any increase in the surface area of the tube bundle only increased its cost.

As part of the efficiency analysis, we calculated the total pounds of distillate produced per hour; this is a crude measure of pounds of steam condensed by the heat exchanger and, therefore, Btu transferred to sap. This is shown in Table 3 when pounds of water evaporated are compared with pounds of distillate produced with different exchangers. Using the undersized unit, 2,686 pounds of water were evaporated per hour. From this evaporated water, 357.44 pounds of distillate was produced, or 13.3 percent of total evaporation. Increasing the size of the heat exchanger by 250 percent increased total distillate only to 504.79 pounds, or 18.3 percent of the water in the escaping steam.

Specifications for Parallel Flow Exchanger

The surface area of tubing required for efficient preheating of sap depends on the flow rate of sap, velocity of sap through the tubes, and the required inlet and outlet temperature of the sap. The tubes should be of a highly conductive material such as copper, and they must not affect food quality.

The surface area required for a parallel flow system with a constant heat transfer coefficient is a function of sap flow (Fig. 5). On the basis of our tests, we found that a heat transfer coefficient of 200 Btu per hour, per square foot of surface area, is acceptable for raising the temperature of the sap from 40 to 190°F. The size and length of tubing required to maintain a heat transfer of 200 Btu is shown for five flow rates in Table 4.

Heat exchangers can be constructed to increase the flow rate of sap. This is done by adding more tubes, or by increasing the tube size.

Figure 5.—Length of tubing required for parallel flow heat exchangers using different tube diameters at different flow rates.

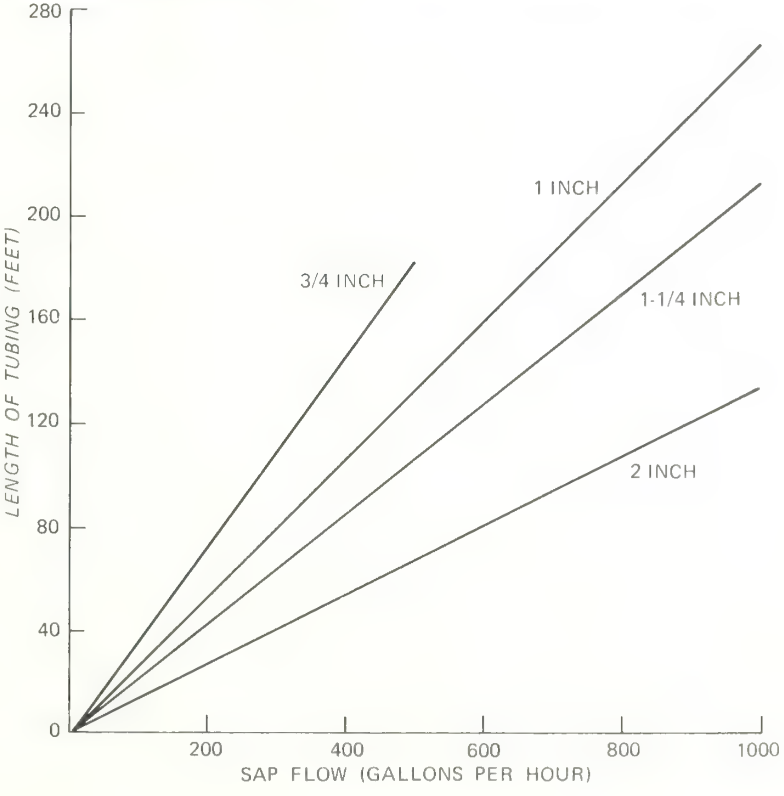


Table 4.—*Specifications for parallel flow heat exchanger on conventional evaporator*[a]

Sap flow (gal/h)	Tube size	Tube length	Manifold	Lateral spacing of tubes	Head	Number of banks	Number of tubes per bank	Diameter of hood stack[b]	Inlet and outlet tube
	Inches	*Feet*	*Inches*		*Feet*			*Inches*	
50	3/4	20	1 1/4	1 3/4	1.2	1	6	6	1
130	3/4	48	1 1/4	2	1.3	1	8	8	1
370	1	105	1 1/2	2 1/4	1.5	1	12	12	1 1/4
500	1 1/4	106	1 3/4	2 1/4	1.7	1	8	14	1 1/2
1,000	1 1/4	212	2	2 1/4	2.0	2	16	16	1 3/4

[a] Tube slope of 2 to 5 percent, and 1/4-inch pressure relief tube for all flow rates.
[b] With damper.

To maintain the same heat transfer, greater lengths of smaller tubing are required. For example, 48 feet of 3/4-inch tubing is required for a sap flow of 130 gallons per hour. If 1-inch tubing is used, only 35 feet are required.

A parallel flow heat exchanger using 1-inch tubes is shown in Figure 6. The unit has 1 1/2-inch manifolds connecting ten 1-inch tubes. Although boxed manifolds are shown, tubular manifolds were also used. The diameter of inlet and outlet piping from manifolds is always 1/4 inch smaller than the manifold, or 1 1/4 inches for the unit shown. A 3-inch curved copper tube (1/4-inch inside diameter) located at the top of the outlet end of the heat exchanger will prevent air from becoming trapped in the unit. All tubes should be installed with a 2- to 5-percent slope to ensure efficient operation. Head requirements for series and parallel flow exchangers using different tube diameters are shown in Figure 7.

An additional attribute of the prototype parallel exchanger is its adaptability. This heat exchanger is designed to be suspended from the inside of any hood, or to be freestanding above the sap pan.

A final modification that improves the operation of this heat exchanger is a damper. The damper assembly is installed in the stack, 18 inches above the ridge of the hood, so that a slight positive pressure is maintained in the hood. The pressure prevents cold air from leaking into the hood and around the tube bundles, which can

Figure 6.—A commercial design of the parallel flow heat exchanger design show: a) Sap inlet; b) Connector manifold; c) Tube bundle; d) Pressure release tube; e) Drip pan; f) Drip pan drain; g) elevating rods; h) Sap outlet.

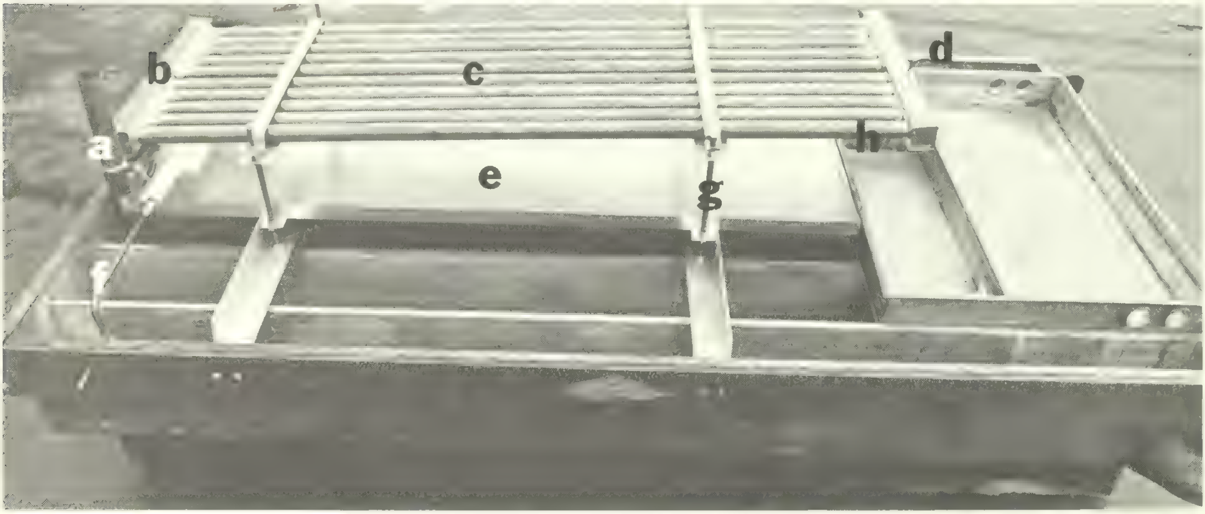
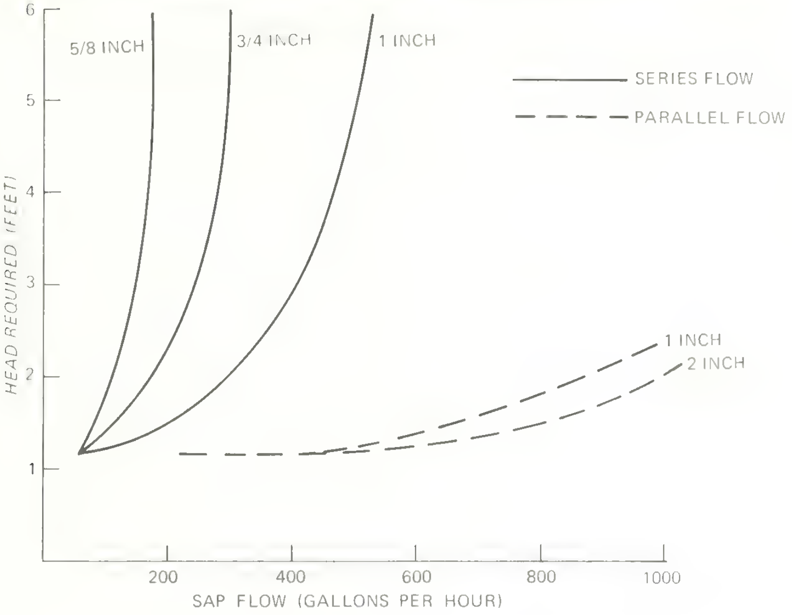


Figure 7.—Head requirements for series and parallel flow heat exchangers using different tube diameters.



reduce efficiency significantly. The damper can be adjusted properly by closing it until a whiff of steam is emitted from the hood base.

Effect of Heat Exchanger on Quality of Syrup

The preheating of sap differs only slightly from the normal treatment of sap in the evaporation process. Heat is applied through a contact vessel made of copper rather than English tin or stainless steel. Analysis of syrup produced with and without a heat exchanger indicated that preheating had no significant effect on the physical or chemical properties or the flavor of the syrup (Table 5). We expected that some copper might be leached from the surface of the tubes, but tests showed that the copper content of the syrup from evaporators with and without the exchanger was virtually identical.

A second question concerned the effect of deposits in the heat exchanger tubes on syrup quality over time; but an analysis of deposits from tubes used to preheat 15,000 gallons of sap showed that the deposits were the same as those that usually occur as scale in the evaporator pan.

ECONOMIC RETURN FROM HEAT EXCHANGER

There are many ways to analyze a capital investment such as a heat exchanger; we demonstrated the effect of the exchanger on the annual net profit of a typical maple producer. Let's first look at this typical operation and its mix of costs and revenues.

Manufacturing Costs

Huyler's 1974 economic analysis of sap collection systems showed that the average annual cost of getting 35 gallons of sap to the sugarhouse is \$3.36.[2] Stated differently, the cost of producing a gallon of 2.5°Brix sap and delivering it to the sugarhouse is approximately \$0.10.

Huyler's[2] analysis of processing costs showed an average annual cost of \$2.96 in processing 35 gallons of 2.5°Brix sap to produce 1 gallon of 66.5°Brix syrup. These costs would be incurred by an operator producing approximately 750

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[2] Huyler, Neil K. 1976. Cost and return estimates for maple syrup operations. Unpublished report. Data on file at George D. Aiken Sugar Maple Laboratory, Burlington, Vt. 05401.

Table 5.—*Analysis of pure maple syrup processed in conventional evaporator with and without a heat exchanger*

Statistic	pH	Sugar concentration	Invert sugars	Phenols	Amino nitrogen	Mineral salts				Light transmittance[f]
						Fe	Zn	Pb	Cu	
		Percent				*ppm*				
					WITH HEAT EXCHANGER[a]					
Mean (x)	6.925	66.1	0.36	779.33	159.92	1.025	3.958	0.292	0.68	591.67
Standard deviation (SD)	.503	.847	.182	270.41	45.39	.615	1.13	.505	.162	281.90
Variance (s^2)	.253	.718	.033	73122.33	2060.45	.378	1.277	.255	.026	79469.70
					WITHOUT HEAT EXCHANGER[b]					
Mean (x)	7.23	65.01	.27	679.87	150.40	1.18	3.74	.380	.614	432.13
Standard deviation (SD)	.40	1.75	.204	156.57	53.98	.96	.837	.487	.174	246.12
Variance (s^2)	.16	3.08	.042	24513.27	2913.83	.93	.701	.237	.030	60573.98
Degrees of freedom[c]	25	25	25	25	25	25	25	25	25	25
t value[d]	2.060	2.060	2.060	2.060	2.060	2.060	2.060	2.060	2.060	2.060
Computed t	1.781[e]	1.976[e]	1.203[e]	1.205[e]	.488[e]	.483[e]	.577[e]	.460[e]	1.008[e]	1.569[e]

[a] 12 samples.
[b] 15 samples.
[c] $n_1 + n_2 - 2$; 12 + 15 - 2 = 25.
[d] t value at 10 percent level of confidence.
[e] Not significant.
[f] 560 nanometers with 1 cm cell.

gallons of syrup per year from 25,800 gallons of sap.

However the above costs have increased radically since 1974; the processing cost has increased to $4.29 per gallon, and the sap production cost has increased to $3.76 (Table 6). Current total manufacturing costs are $8.05 per gallon, or $0.73 per pound. The greatest increase in processing costs is due to increased fuel prices. The price of No. 2 fuel oil in the Northeastern and North Central U.S. rose from $0.28 per gallon in 1974 to $0.48 per gallon in 1977.

Approximately 4 gallons of oil are used in processing 1 gallon of syrup; so the cost of producing a gallon of syrup has increased by $0.80 since 1974 due to fuel alone. Equipment prices have increased by 15 percent per year, and labor and material cost increases have averaged 8 percent per year, with additional increases of at least 6 percent per year expected over the next 2 years.

Most new technology offers a firm an option; it can use the technology to reduce costs or to increase production. Generally, the overall impact of new technology is greater if it is used to expand production.

Reducing Costs

A heat exchanger reduces labor and fuel requirements if used to reduce costs, and if syrup production is maintained at the same level. An analysis of a firm producing 750 gallons of syrup shows that the use of a heat exchanger increases capital costs but reduces labor, energy, and miscellaneous costs; the exchanger increases the hourly evaporation rate and syrup production by about 15 percent, thus reducing processing time.

A reduction in labor and energy requirements reduced processing costs by $0.16 for each gallon of syrup produced; there was no reduction in sap production costs. The total cost of producing 750 gallons is $7.89 per gallon versus $8.05 without a heat exchanger (Table 6).

Increasing Production

Greater savings can be realized if new technology is used to increase production. When a heat exchanger is used, production can be increased without increasing the size of the plant. When production is increased, total costs are increased, but more syrup is produced; so the cost per gallon is reduced.

Table 6.—*The effect of a heat exchanger on annual costs of maple syrup production*[a]

Item	Unit value	Useful life	Annual cost without heat exchanger (per gallon of syrup)[b]	Annual cost with heat exchanger (per gallon of syrup)	
				Maintain production	Increase production 15%
	Dollars	*Years*	*Dollars*		
ap production costs:					
Equipment	6,113.00	—	1.34	1.34	1.34
Orchard rental ($0.11/tap)	—	—	.44	.44	.44
Materials	—	—	.22	.22	.22
Labor ($2.75/h and 9.6 min/tap)	—	—	1.76	1.76	1.76
		Total	3.76	3.76	3.76
rocessing costs:					
Land	1,000.00	25	0.15	0.15	0.13
Building	2,387.00	25	.35	.35	.31
Equipment	8,278.00	20	1.30	1.30	1.13
Heat exchanger	877.00	20	—	.20	.12
Labor	—	—	.53	.46	.46
Fuel	—	—	1.92	1.63	1.63
Other	—	—	.04	.04	.04
		Total	4.29	4.13	3.82
	Total manufacturing costs		8.05	7.89	7.58

[a] Assumes a 3,000 tap operation producing 25,800 gallons of 2.5° Brix sap and 750 gallons of syrup (costs are 1977 market values).
[b] Assumes 34.3 gallons of sap equals 1 gallon of syrup.
[c] Assumes a 15 percent increase in sap and syrup production (25,800 X 1.15 = 29,670 gallons of sap; 750 X 1.15 = 862 gallons of syrup).

To increase production, more sap is needed from the woods; to match the 15 percent increase in syrup production, attainable by adding a heat exchanger, the number of taps must be increased by 15 percent. Although it is conceivable that a 25 to 50 percent increase in the number of taps would gain a significant economy of scale, and therefore, lower the sap cost, a 15 percent increase is not likely to lower the cost per tap (Huyler 1975; Gunter and Koelling 1975). So the cost per gallon on sap produced remains the same (Table 6).

Syrup processing costs will increase, but only in the amount of the amortized costs for new equipment (heat exchanger). The annual amortized cost of an exchanger for a 3,000-tap bush is $103. However, this cost is allocated to a larger production base of 862 gallons of syrup (750 X 1.15). Therefore the total annual cost per gallon of syrup is reduced to $7.58 or $0.69 per pound; unit costs are reduced by $0.39 per gallon, or by 6 percent, and total manufacturing costs are reduced by 3 percent.

CONCLUSIONS

The use of a heat exchanger improved the efficiency of the open-pan evaporator:

- In the evaporators that operated at 74 percent efficiency, 16.6 percent of the energy loss was to stack gas. Research is needed to reduce the energy loss from this source.
- When sap was preheated, the efficiency of the evaporator was increased by 15 to 17 percent.
- A parallel flow heat exchanger is more versatile than a series flow exchanger because it is easily vented, the tube surface area can be increased more easily for larger evaporators, one size of tubing can be used for units of any size, and head restrictions can be accommodated easily.
- The use of a heat exchanger does not affect the quality of syrup.
- When a heat exchanger is used, processing costs can be reduced by 6 percent, and total costs by 3 percent, without increasing the size of the plant.

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1977. **Increasing the efficiency of maple sap evaporators with heat exchangers.** Northeast. For. Exp. Stn., Upper Darby, Pa. 12 p., illus. (U.S. Dep. Agric. For. Serv. Res. Pap. NE-388)

A study of the engineering and economic effects of heat exchangers in conventional maple syrup evaporators indicated that: (1) Efficiency was increased by 15 to 17 percent with heat exchangers; (2) Syrup produced in evaporators with heat exchangers was similar to syrup produced in conventional systems in flavor and in chemical and physical composition; and (3) Heat exchangers reduce per unit production costs, and can yield greater production and higher profits.

Keywords: maple syrup production, processing, economics of processing, costs of processing

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TRAIL TRANSECT:

A Method for Documenting Trail Changes

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By R. E. Leonard and A. M. Whitney

FOREST SERVICE RESEARCH PAPER NE-389
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
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ABSTRACT

A trail transect system that documents trail conditions and changes in trails has been used successfully over the past 3 years to measure soil loss, and changes in trail width and vegetation. The system also can be used to study the relationship between trail degradation and the physical characteristics of a site. Data from trail transects can be useful in determining the physical conditions favorable for trail construction.

INTRODUCTION

DURING A STUDY of the impact of hikers on trails in the high-peaks region of the Adirondack Mountains in New York, Ketchledge and Leonard (1970) established trail transects to document trail conditions and to monitor physical changes on hiking trails. Work to date has resulted in a transect system that has been used successfully over the past 3 years to measure soil loss, and changes in trail width and vegetation (Fig. 1).

In this paper we describe how to set up a series of permanent benchmarks along a trail (ground control), choose sites for study, set up transects, and collect and compare information from the transects accurately. However it should be noted that this system does not attempt to point out the "whys" and "hows" of trail degradation.

TRAIL TRANSECT SYSTEM

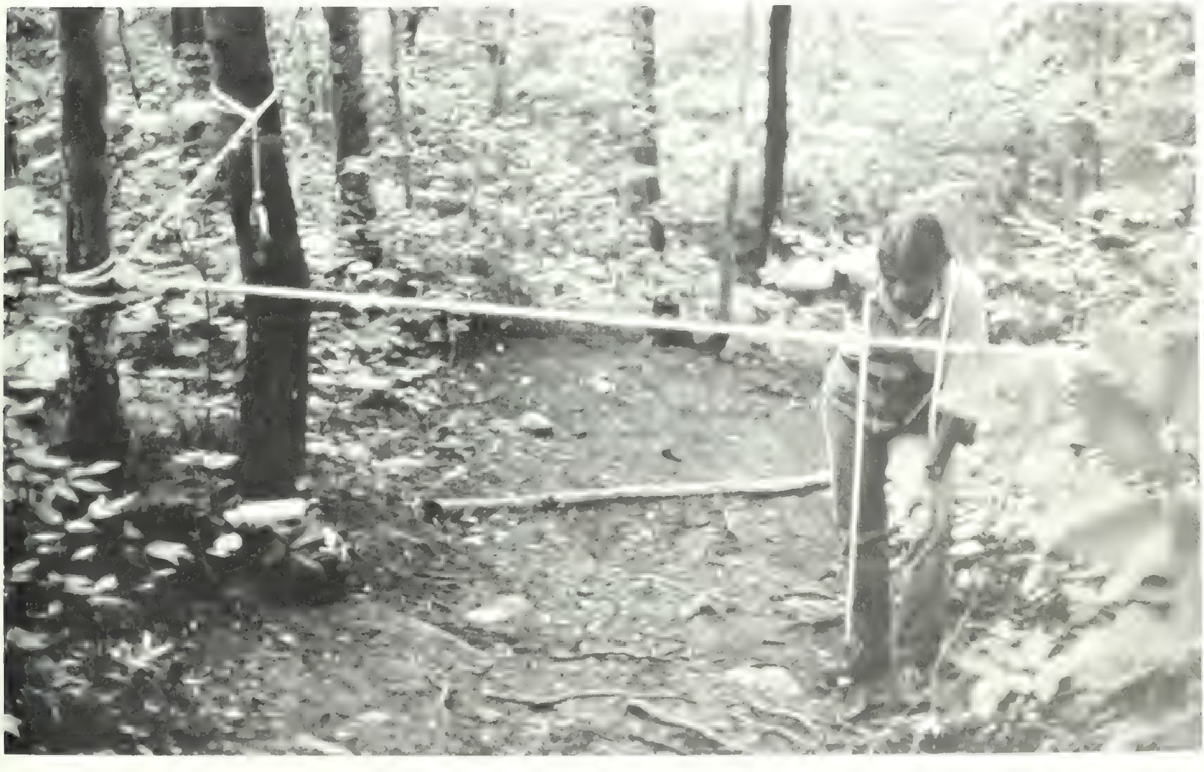
The system is a series of transects, located selectively along a trail. Transect locations should reflect the physical characteristics of the trail. At each transect, soil movement and changes in trail width and vegetation are monitored. The system is designed to facilitate accurate resampling of each transect, yearly or biyearly (spring and fall).

Ground control

Basic to most field measurements is a reliable system of ground control for relocating sample points. Our ground control method provides a series of permanent benchmarks that can be used to locate the transects.

Begin by placing a permanent marker on a single tree at the trailhead. A lagbolt screwed

Figure 1.—A trail transect being used in the field.



into the tree at a height of about 4-1/2 feet (breast height) works well. In a field notebook record the tree species, diameter at 4-1/2 feet (dbh), and the tree's location in relation to the trailhead.

Using this marker as the origin of the ground control system, run a highway-distance measuring wheel (cyclometer) up the center of the trail, nailing numbered aluminum tags to trees at intervals of approximately 100 meters. Walking slowly with the wheel produces the best results. At each 100-meter point, nail a numbered tag to the trailside base of the nearest tree on the left side of the trail. At each point record the tag number, the tree species, the dbh, and the distance from the tree to the trail center. It also is useful to determine the elevation at each point; we found that a simple, hand-held altimeter is usually sufficient for documentation.

Repeat this process with the consecutively numbered tags; at the end of the trail, establish a final permanent marker (lagbolt). It is wise to record the location of this marker by identifying the tree species, dbh, and distance from the tree to the previous aluminum tag.

The following is an example of field notes on the location of ground control tags:

Site selection

To monitor a trail system effectively, select transect sites that reflect a range of physical characteristics, including slope, elevation, soil, water, and degree of damage encountered on the trail.

Transect sites also should have a significant degree of remeasurability. Points of extreme irregularity, such as the brink of a trench, a steep ledge, or deep-standing water, should be avoided. Moving the transect line to either side of these obstacles will provide a more accurate sampling of the site by partially eliminating ambiguities in measurements; for example, was the top or the bottom of the trench sampled last year?

However do not select an unreasonably large number of transect sites in an effort to represent all trail conditions; this system was developed only to indicate critical trail conditions and changes. In one of our investigations we used a total of 35 transects on a two-mile trail in New England; conditions ranged from poorly drained (wet) soil to exposed bedrock, hardwood forest to subalpine spruce, and 1,000- to 3,000-foot elevations.

Point	*Elevation (feet)*	*Side of trail*	*Species*	*Dbh (inches)*	*Remarks*
1	1,950	Left	Spruce	6	On a tree with an arrow pointing to the trailhead. About 15 meters from the first "Y" in the trail.
2	1,980	Left	Maple	10	On the opposite side of the trail is a tree with a WMNF sign.
3	2,020	Right	Maple	10	There is a large boulder on the opposite side of the trail.
4	2,070	Left	Maple	8	This is at the beginning of a steep incline.

Establishing trail transects

To set up a trail transect, a second set of numbered aluminum tags is needed. Select two trees, one on each side of the trail (but preferably a short distance from the trail edge), so that the line between the trees crosses the trail roughly perpendicularly. Place a numbered tag on the left-hand tree (facing upslope) 4-1/2 feet from the base. Record the distance in meters from the tree to the nearest ground control tag. Drive a galvanized nail into the downslope side of the tree, about waist high. Then tie a string to the nail and extend it across the trail to the right-hand tree, adjusting the line so that it is roughly parallel to the trail. At this point, drive a nail into the tree on the right; record the species and dbh of both trees. Also note the elevation and the distance from the trees to manmade structures, such as waterbars or steps, that are upslope of the transect (Fig. 2). (See the Appendix for a list of transect equipment).

Measurement procedures

Two fiberglass metric tape measures are required at a transect site. One is extended between the two trees and serves as a horizontal measure across the trail. The second tape, equipped with a plumb bob suspended from the end, is used for vertical measurements along the horizontal axis.

Before taking measurements, it is important to record the distance between the "O" point, or beginning of calibration, and the end of the tape. For the vertical tape, record the distance between the "O" point and the end of the plumb bob (Fig. 3). These distances should be the true distances; this step will ensure that future readings are comparable, even if different tapes are used.

The horizontal tape is set up from the tree on the left to the tree on the right. Slip the hook of the tape over the left nail and wrap the tape around the tree counterclockwise; then pass the tape under the nail and extend it over to the other tree. Again, pass the tape under the nail and draw it taut; then wrap it repeatedly around the tree and tie it off. Record the points where the tape passes under the nails; they are important in realigning the tape for future measurement (Fig. 4). Since the tape tends to sag, loop a length of carpet string over the nails and draw it taut. All vertical measurements should be taken from the top of the string (Fig. 5).

Figure 2.—An illustration of a trail transect.

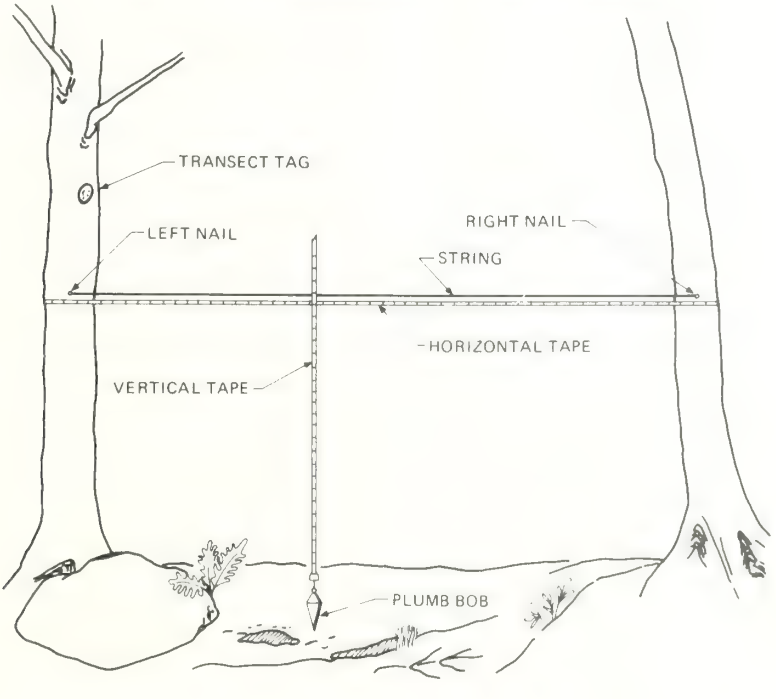


Figure 3.—It is important to record the distances between the "O" points and the ends of the horizontal and vertical tapes.

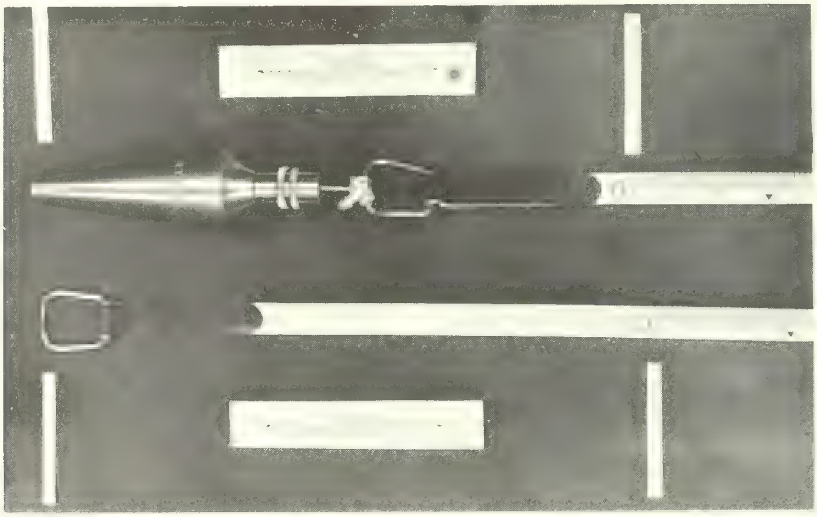


Figure 4.—An example of left nail reading of 34.6 cm.

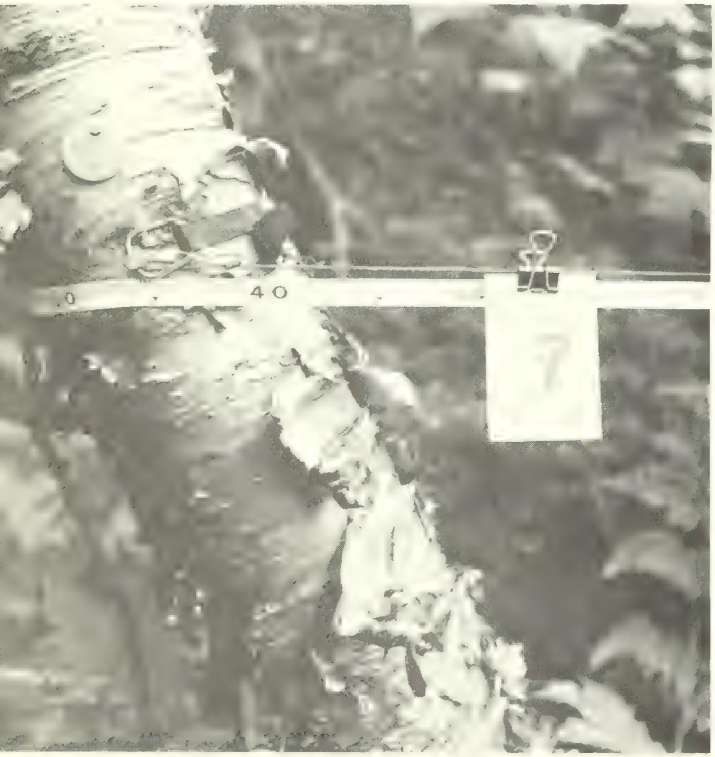
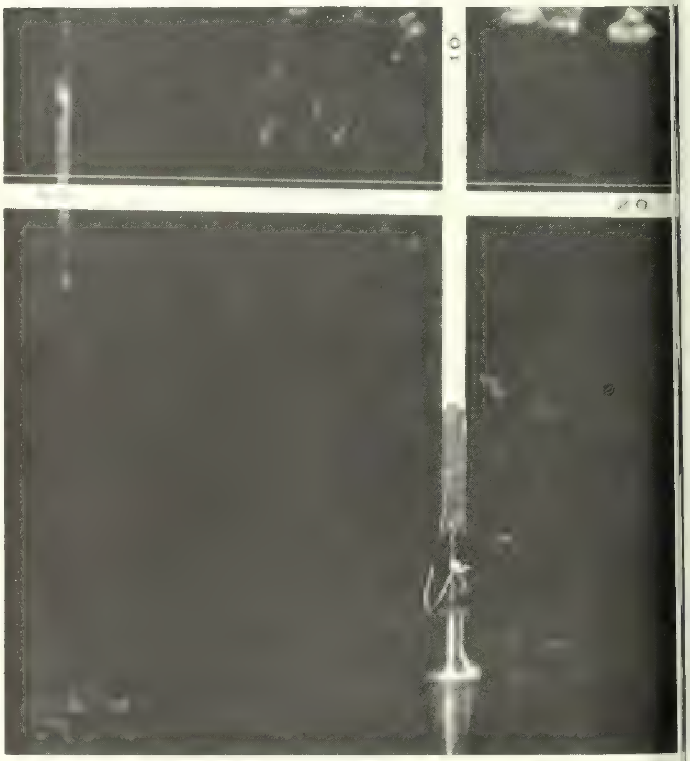


Figure 5.—An example of vertical measurement
3.4 cm.



Trail boundaries

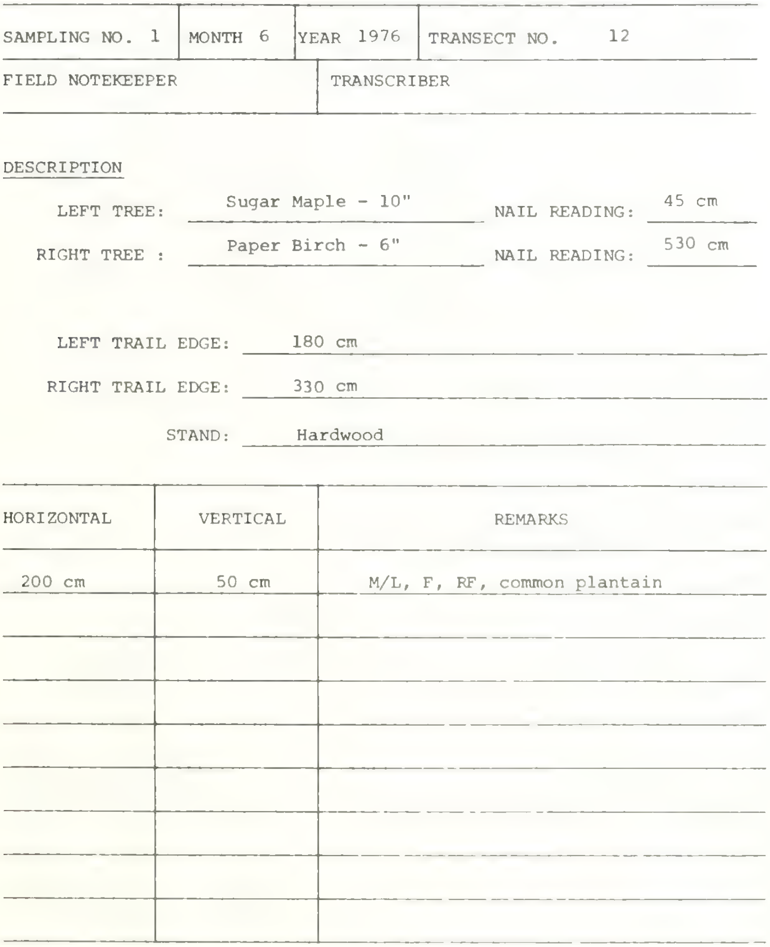
The first measurements establish the horizontal position of the trail edges. Suspend the plumb bob along the horizontal tape so that its point lies directly over the trail edge. The trail edge boundary is the point between the exposed soil or bedrock, which may be more accurately described as the immediate treadway, and the trailside vegetation. Record the two readings on the horizontal tape where it is intersected by the plumb bob string to indicate the position of the edges. We usually begin the remaining readings 20 to 40 cm outside the trail edges to allow for future widening.

Trail profile

After selecting the total horizontal distance to be measured, take vertical measurements at intervals of 5 or 10 cm along the horizontal tape. These measurements, taken from the ground surface to the carpet string, provide a rough profile, or cross section, of the trail. We have found that considerable practice is required to suspend the plumb bob on the surface of the ground, hold it at a known horizontal, and then read the vertical distance. The most consistent results probably are obtained when the eyes are at the level of the string, though this is not the most comfortable position.

At each point where a vertical measurement is taken, record the vegetation (ground cover species) and surface soil characteristics within 5 cm of the plumb bob point. Also record, once for each transect, the forest stand surrounding the transect site. In our example of the fieldbook notes (Fig. 6), the forest stand has been recorded as hardwood; the ground vegetation at this par-

Figure 6.—Example of trail transect fieldbook notes.



SAMPLING NO. 1 | MONTH 6 | YEAR 1976 | TRANSECT NO. 12

FIELD NOTEKEEPER | TRANSCRIBER

DESCRIPTION

LEFT TREE: Sugar Maple - 10" NAIL READING: 45 cm

RIGHT TREE : Paper Birch - 6" NAIL READING: 530 cm

LEFT TRAIL EDGE: 180 cm

RIGHT TRAIL EDGE: 330 cm

STAND: Hardwood

HORIZONTAL	VERTICAL	REMARKS
200 cm	50 cm	M/L, F, RF, common plantain

ticular spot (horizontal: 200 cm; vertical: 50 cm), is represented by common plantain. A more detailed description might be developed, but this system is sufficient for documentation.

To document surface soil characteristics, we have developed a simplified system that is based on the exposure of mineral soil versus soil covered with organic matter (leaf litter), the extent to which the organic matter is visibly decomposed, and the physical nature of the rock that might be present. As with the system for recording vegetation, this is a qualitative method, but it can be used with minimum training. In the example of fieldbook notes, the surface soil on the site is a mixture of mineral soil and litter (M/L), the litter is fractured (F), and there are rock fragments (RF) (Fig. 6).

The following criteria should be used for documenting the forest stand, surface soil characteristics, and rock on a transect site:

Forest Stand

Hardwood (H)	Minimum of 90% trees hardwood species.
Softwood (S)	Minimum of 90% trees softwood species.
Mixed (H/S)	Less than 90% hardwood and less than 90% softwood.

Surface Soil

Mineral (M)	Minimum of 90% area exposed mineral soil.
Mixed (M/L)	Less than 90% mineral soil and less than 90% litter.
Litter (L)	Minimum of 90% area covered by organic matter (leaves, twigs, needles).
Unfractured (UF)	Minimum 95% entire, not broken, origin recognizable.
Fractured (F)	Minimum 75% not entire, broken, but origin still recognizable.
Finely ground (FG)	Minimum 95% finely divided, origin no longer recognizable.

Rock

Rock fragment (RF)	Loose rock, easily disturbed.
Embedded rock (ER)	Held in place by soil, not easily disturbed.
Bedrock/ledge (B/L)	Portion of underlying rock formation.

DATA EVALUATION

The data obtained from a transect may be compiled on a desk calculator (Fig. 7).

Trail width

The change in trail width is monitored by the horizontal readings. In a given transect, the tread might extend from 220 cm to 350 cm one year, then expand to extend from 190 cm to 380 cm the next. If care is taken in resetting the horizontal tape, this method graphically records any change in width. Where there is no clearly defined transition point, or where subjective differences arise between individuals sampling, the recorded descriptions of surface soil conditions are usually sufficient for documentation.

Soil loss

The vertical measurements are used to monitor soil loss. Once these measurements are adjusted for any change in plumb bob position from year to year, they can be inserted into the following equation to calculate the area (A) from the string to the ground surface within the zone measured:

$$A = \frac{V_1 + V_2}{2} + \frac{V_2 + V_3}{2} + \frac{V_n + V_{n+1}}{2} \times D$$

Where: A = area in square centimeters

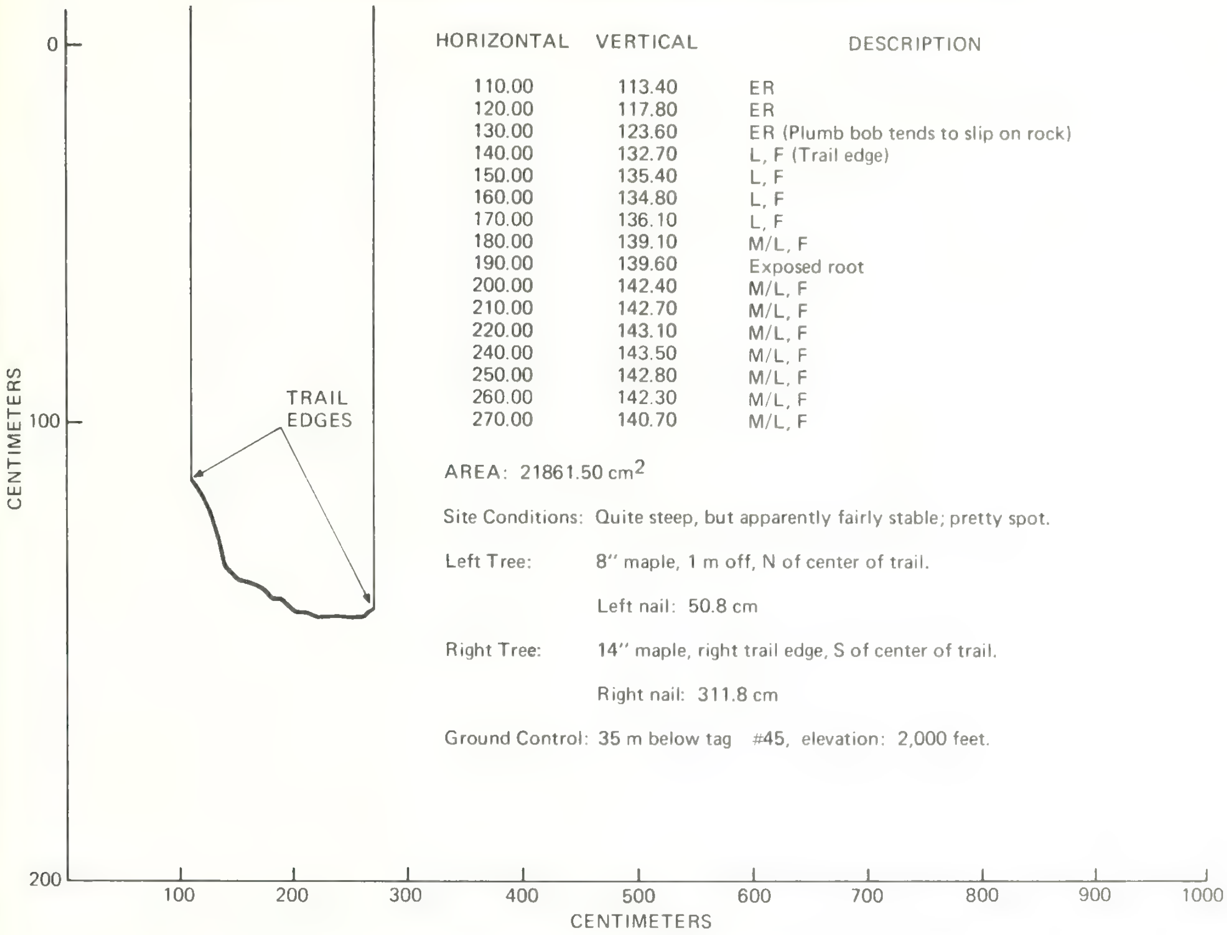
V_n = vertical distance measurements (cm)

D = interval on horizontal axis (5 or 10 cm).

An increase in area from one year to the next at an individual site indicates soil loss (Fig. 8).

To evaluate erosion in a transect, area calculations from seasonal or yearly samplings are compared. However, two figures for area can be compared only when the same horizontal readings are used for both area calculations (to ensure that the same horizontal span, or trail width, is being compared). As the characteristics of the tread change, comparisons can be made using a new horizontal span. So vertical measurements taken initially outside

Figure 7.—An example of compilation of trail transect data.



HORIZONTAL	VERTICAL	DESCRIPTION
110.00	113.40	ER
120.00	117.80	ER
130.00	123.60	ER (Plumb bob tends to slip on rock)
140.00	132.70	L, F (Trail edge)
150.00	135.40	L, F
160.00	134.80	L, F
170.00	136.10	L, F
180.00	139.10	M/L, F
190.00	139.60	Exposed root
200.00	142.40	M/L, F
210.00	142.70	M/L, F
220.00	143.10	M/L, F
240.00	143.50	M/L, F
250.00	142.80	M/L, F
260.00	142.30	M/L, F
270.00	140.70	M/L, F

AREA: 21861.50 cm^2

Site Conditions: Quite steep, but apparently fairly stable; pretty spot.

Left Tree: 8" maple, 1 m off, N of center of trail.

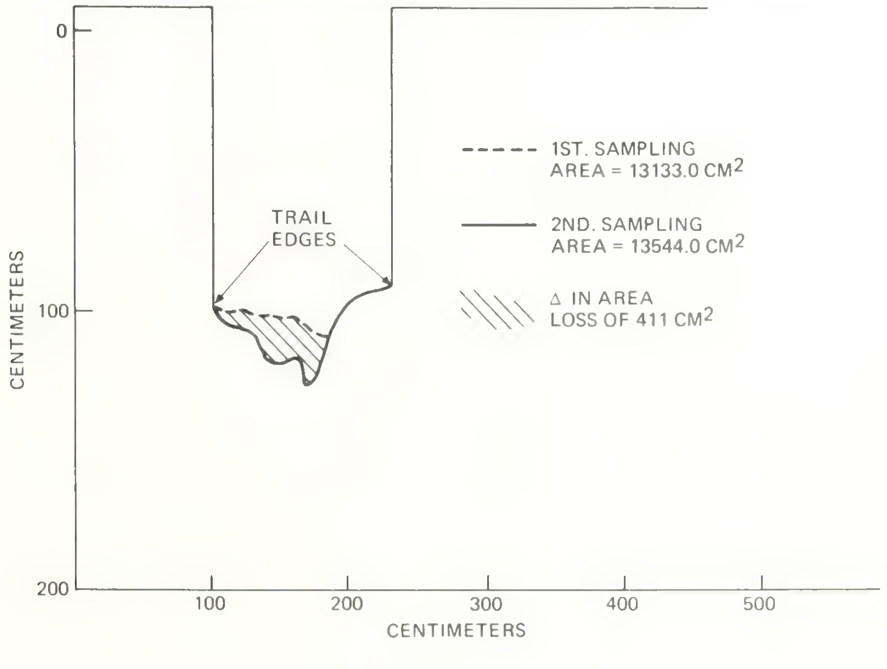
Left nail: 50.8 cm

Right Tree: 14" maple, right trail edge, S of center of trail.

Right nail: 311.8 cm

Ground Control: 35 m below tag #45, elevation: 2,000 feet.

Figure 8.—An example of calculation of soil loss on trails.



the tread can become important later when the tread has widened to encompass them.

A larger comparison of erosion along a trail can be obtained by a further breakdown of the area figure. Since the tread width measured for erosion depends on the nature of the transect site, the change in area (loss or gain) in cm^2 per horizontal span must be calculated for comparisons between transects. For our calculations, a 10-cm span is used. The trail width is divided into 10-cm intervals, and the change in area is divided by the number of intervals. The result is an average change in area in cm^2 per 10-cm interval.

Change in vegetation

The change in vegetation at a transect is evaluated by determining the presence or absence of plants or species from one sampling to the next.

This information is also helpful in monitoring trail widening, or shifts in the location of the tread. A new trail could be documented by observations of losses of vegetation and changes in surface soil within the transect but not on the immediate tread.

It should not be assumed that the species list collected from a transect represents all of the species on the mountain. Often, trails receive more sunlight than the adjacent land; this provides habitats for uncharacteristic species. Trails also are subjected to impact pressures that can keep common woodland species off them.

CONCLUSION

The application of information from transects does not stop with documentation of trail conditions and changes in trails; the data can be used to study the relationship between trail degradation and the physical characteristics of a site.

Data from the trail transect system—which can be used by individuals with little professional training—also can be useful in determining the physical conditions favorable for trail construction. This information could be used directly in the design and location of new trails, and the reconstruction of existing trails.

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APPENDIX

Equipment list for establishing trail transects

- 2 sets of numbered aluminum tags
- 2 lagbolts
- Highway distance-measuring wheel (cyclometer)
- Notebook
- Simple altimeter
- Carpet string
- 2 fiberglass metric tape measures
- Plumb bob
- Hammer

Leonard, R. E., and A. M. Whitney.
1977. **Trail transect: a method for documenting trail changes.**
Northeast. For. Exp. Stn., Upper Darby, Pa.
8 p., illus. (U.S. Dept. of Agric., For. Serv. Res. Pap. NE-389)

A trail transect system that documents trail conditions and changes in trails has been used successfully over the past 3 years to measure soil loss, and changes in trail width and vegetation. The system also can be used to study the relationship between trail degradation and the physical characteristics of a site. Data from trail transects can be useful in determining the physical conditions favorable for trail construction.

424.1:116.6

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- Warren, Pennsylvania.

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Impact of Alternative Timber Management Policies on Availability of Forest Land in the Northeast

FOREST SERVICE RESEARCH PAPER NE-390
1977

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
NORTHEASTERN FOREST EXPERIMENT STATION
370 REED ROAD, BROOMALL, PA 19008

The Author

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ABSTRACT

Gaging the ability of the forest resource to satisfy future timber requirements is central to solving many problems arising from competition for use of forest land. In this study, production potentials of forest acreage in the Northeastern United States under management alternatives that range from extensive to intensive are weighed against several estimates of timber requirements for the year 2000. The different capabilities for fulfilling timber requirements in different parts of the region indicate areas likely to be affected most by further shifts toward nontimber use of forest land.

The intermediate option for forest management combines forest management at the present level with emphasis on harvesting the best timber-growing sites first. This option could meet timber requirements for year 2000 with roughly half the region's commercial forest area. Moreover, it could accommodate both intensive management and multiple-use objectives where they are most applicable by allowing flexibility in forest land use decisions.

COMPETITION for use of forest land, already very evident in parts of the Northeast, will become especially keen in the future—keener, on the whole, than the competition for the wood that the forests can produce. Yet, as others (Clawson 1974, Zivnuska 1974) have suggested, the way to resolve the land use conflicts may be to increase wood production—simply because increased wood production could satisfy the demand for timber with less commercial forest area. And this would provide greater flexibility in the use of forest land for purposes other than timber production.

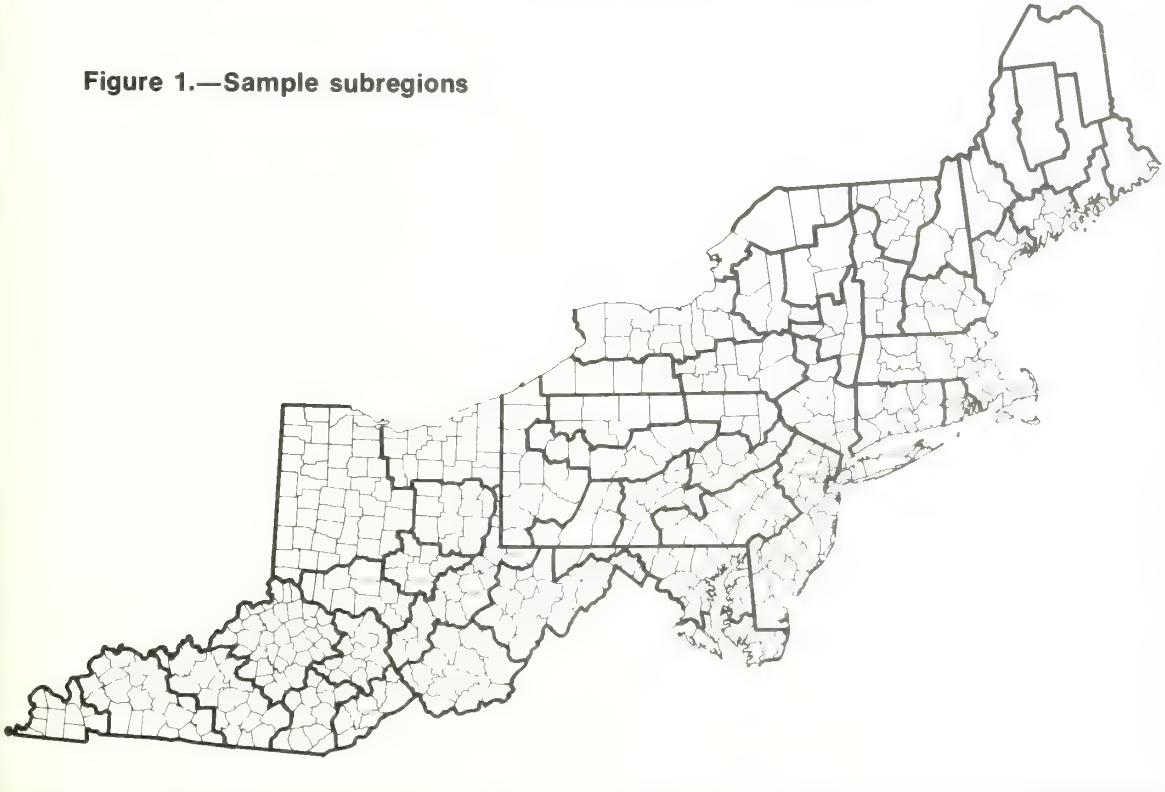
If there were general agreement on a long-run program for growing timber, many problems arising from timber harvesting and from competition for forest land would be easier to solve. Thus it seems desirable to take a look at alternative long-run timber-growing programs, and then work backward to the actions indicated on today's forests. Recent projections of national timber requirements (U.S. Forest Service 1973, 1976) provide a framework for regional assessments and for describing some likely supply-demand relationships and their implications for the future.

PROJECTING WOOD FIBER NEEDS

Average annual removals of merchantable trees in subareas of the Northeastern U.S. (Fig. 1) have been linked to the national demand for timber projected under various price assumptions in the 1975 assessment of the Nation's renewable resources (U.S. Forest Service 1976). These projections are based on medium growth in population and economic activity.

One demand projection was developed under the assumption that 1970 price relationships would not change significantly during the projection period; this resulted in high estimates of

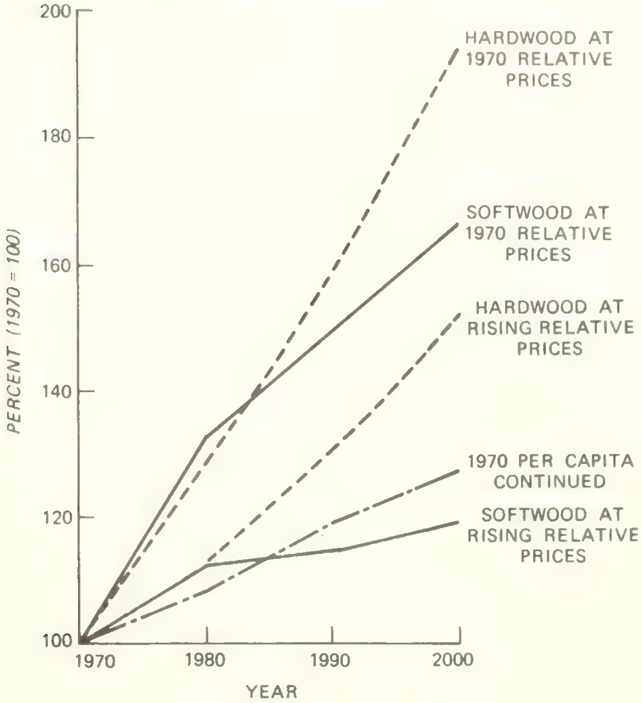
Figure 1.—Sample subregions



timber products consumption in terms of roundwood volume. Another projection, which recognized the likelihood of future price increases, had relative prices rising from 1970 levels by 1.5 percent per year for lumber; 1.0 percent per year for plywood, miscellaneous products, and fuelwood; and 0.5 percent per year for paper and board. These prices resulted in lower levels of consumption than in the first projection. A third projection is based on recent trends in U.S. per capita consumption of timber. Consumption of wood increased more rapidly than population until shortly after the turn of the century; then the increase slowed until it now approximates population growth. Per capita consumption has remained about the same for 2 decades (Radcliffe 1976).

To estimate future timber demands for each State and forest survey subregion, the average annual timber removals in 1970 were multiplied by an index of the projected national increase in demand (Fig. 2). This generates a set of demand projections for the subregions consistent with the two "assessment" assumptions. To derive the third demand projection, the medium projection of U.S. population growth (U.S. Bureau of the Census 1975) was converted to an index (1970 = 1.00) and applied to the recent average annual timber removals. This projection assumes a continuation of current removals per capita and an increasing U.S. population.

Figure 2.—Projected change in timber removal, 1970-2000 (Northern U.S.).



These estimates of future demands for timber, based on proportionate changes in local timber removals, in some sense acknowledge the economic factors underlying productive capacities that have emerged from past demands for wood. Insofar as this represents the region's comparative advantage in producing wood, the assumption of proportionate response, while not totally satisfactory, is the best at hand.

MANAGEMENT ALTERNATIVES

Three broad classes of alternatives for forest land management and timber production seem possible for the coming decades:

- Extensive: low-intensity management with high acreage harvested
- Intensive: high-intensity management with low acreage harvested
- Intermediate: some action in between.

The "extensive" alternative reflects what is now happening in Northeastern forests. Average growth of wood is less than half (42 percent) of the potential of fully-stocked natural stands. Controversy continues over how much forest should be harvested, methods of timber harvest, withdrawal of additional area for nonharvest forest uses, and similar matters. Nevertheless, commercial forest is potentially available for timber harvest and most of it will be harvested at one time or another. A forest management policy based on this "extensive" option would be to continue current management levels and cutting practices, maintaining the cut per acre at its present level.

In contrast to the "extensive" alternative is one that would include some actions to insure nearly complete natural stands of trees: several intermediate cuttings between harvests and the application of special techniques to get rapid stand regeneration. But this is intensive management in a relative sense only: it is not meant to attain the ultimate biological potential for timber production that might be achieved under extremely intensive forest culture.

Rather, this more feasible management policy is designed to promote timber management and harvest on the most productive forest land. Accordingly, it concentrates timber management and cutting practices on the best sites first.

The Forest Service categorizes sites by the mean annual growth in cubic feet per acre attainable in fully stocked natural stands at the culmination of their mean annual increment. Biological potential of the forest is simply an expression of the average growth of wood per unit area of forest land devoted to timber growing. A calculation for the Northeast indicates that the region has a potential productive capability of about 7.03 billion cubic feet per year, if all of the commercial forest area were used to its natural timber-growing capacity (Table 1). A similar calculation using each State and subarea's potential acreage distribution among the site classes provides a gage of its productive capability under intensive management.

Our intermediate alternative for forest land management and timber production would concentrate timber harvest activity on the best sites first, while continuing forest management at present levels. Site classes also provide the basis for gaging productive capability under the intermediate alternative; but based on the area's present, rather than potential, acreage distribution of mean annual growth classes. On this basis the region could grow 3.81 billion cubic feet per year; slightly over half the 7.03 billion cubic feet of *potential* timber-growing capacity.

ble 1.—Potential timber productivity of commercial forest land in the Northeast

ite class[1]	Commercial forest area	Potential annual growth per acre[2]	Total potential annual growth
	M acres	*ft^3*	*Million ft^3*
to 165 ft^3/acre	8621.0	142.5	1228.5
to 120 ft^3/acre	22034.4	102.5	2258.5
to 85 ft^3/acre	37298.1	67.5	2517.6
to 50 ft^3/acre	29209.3	35.0	1022.3
lasses	97162.8	72.3	7026.9

classes indicate potential growth of fully stocked natural

point of the site class.

COMMERCIAL FOREST LAND REQUIREMENTS

The growth figures above contrast with recent levels of timber growth and removal, which are about 2.93 and 1.28 billion cubic feet, respectively. Overall, these data indicate that the Northeast has much unused timber-growing capability. But we must also take account of both the increasing wood fiber requirements that have been projected and the spatial variation in ability to satisfy them throughout the Northeast.

High-level demand

Extensive management. If current practices were continued, the timber resources in some northeastern states would be insufficient to fulfill the higher estimates of roundwood consumption projected (at 1970 relative prices) for the year 2000 (Fig. 3). Hardwood forest management at this extensive level would not sustain enough annual wood production to prevent deficits in Ohio, New York, Maine, Vermont and Maryland. Likewise, the extensive level of management would fail to meet high-level projected requirements for softwood timber in Ohio, New Jersey, Maryland and Delaware. In fact, softwood timber removals have already exceeded growth in the last three of these states.

Deficits between estimated roundwood demand and the amount of wood production that these states could sustain with current cutting practices could be met elsewhere in the region. To do so would require that about 90 percent of the region's hardwood production area and 75 percent of the softwood production area be committed to growing wood.

Intensive management. In sharp contrast, most of the high-level projected demand for wood fiber could be satisfied from a fraction of the commercial forest area if the intensive management alternative were adopted. Only one-fourth of the region's hardwood production area would be needed for timber growing under intensive management. Similarly, softwood requirements could be met with one-fifth of the region's softwood production area. In Delaware and Maryland, however, even intensive management would not prevent a softwood deficit. Other states in the region would have to make

Figure 3.—Proportion of State's commercial forest area needed to meet timber demands projected at 1970 relative prices, for year 2000.

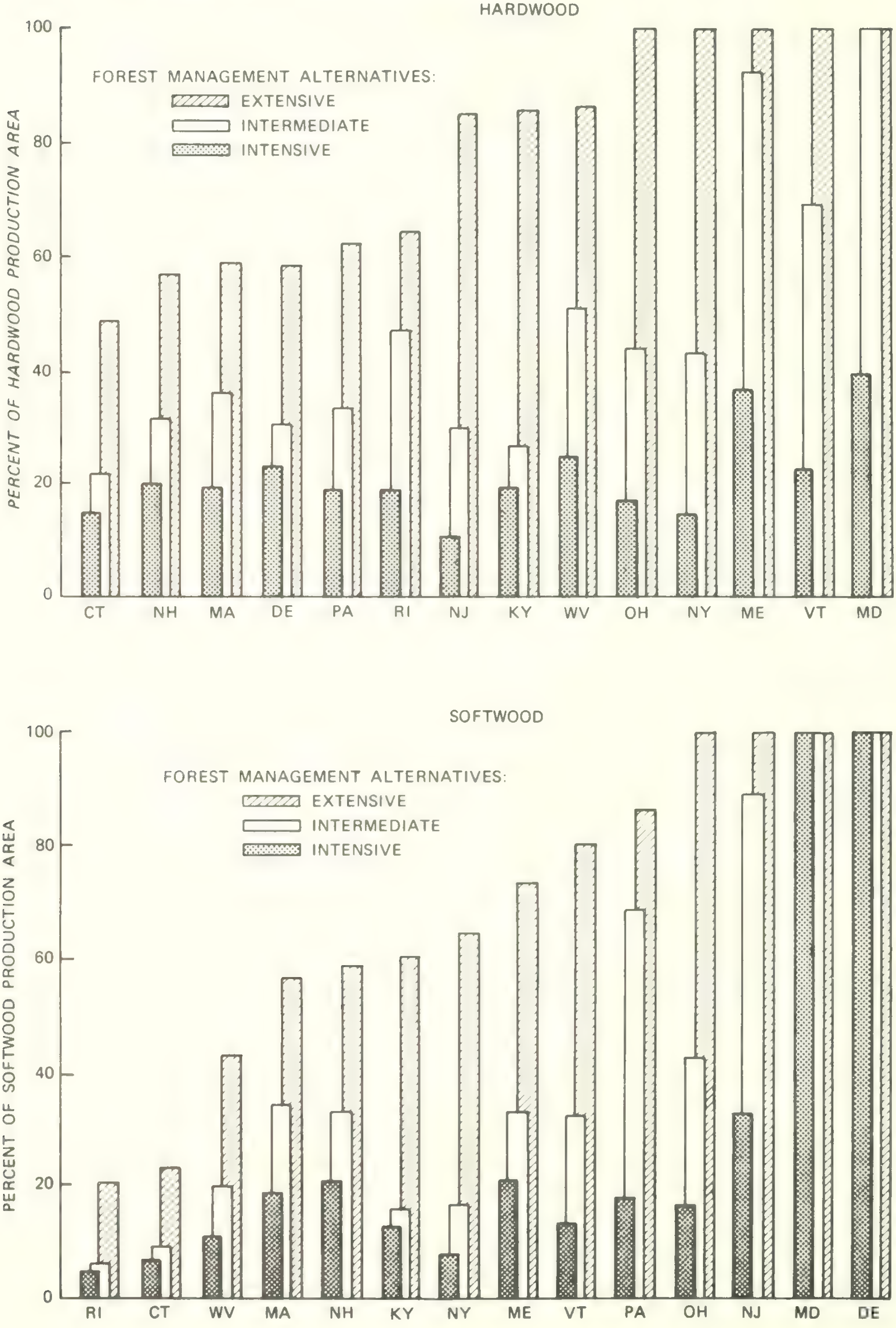
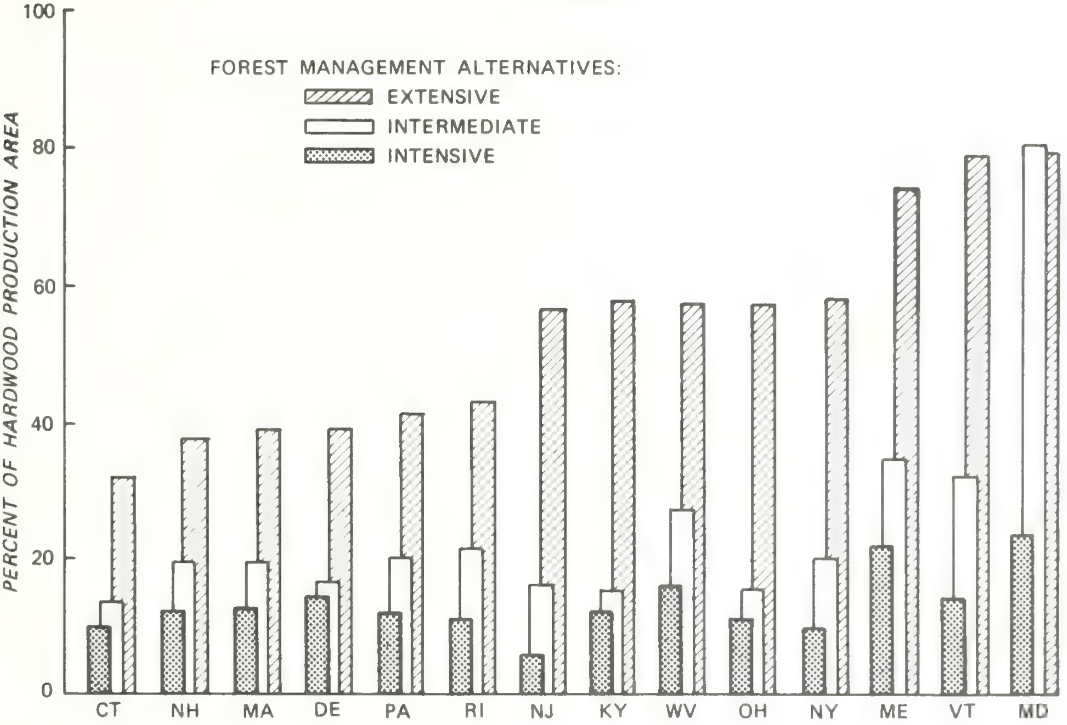


Figure 4.—Proportion of State's commercial forest area needed to meet timber demands projected at current consumption per capita, for year 2000.

HARDWOOD



SOFTWOOD

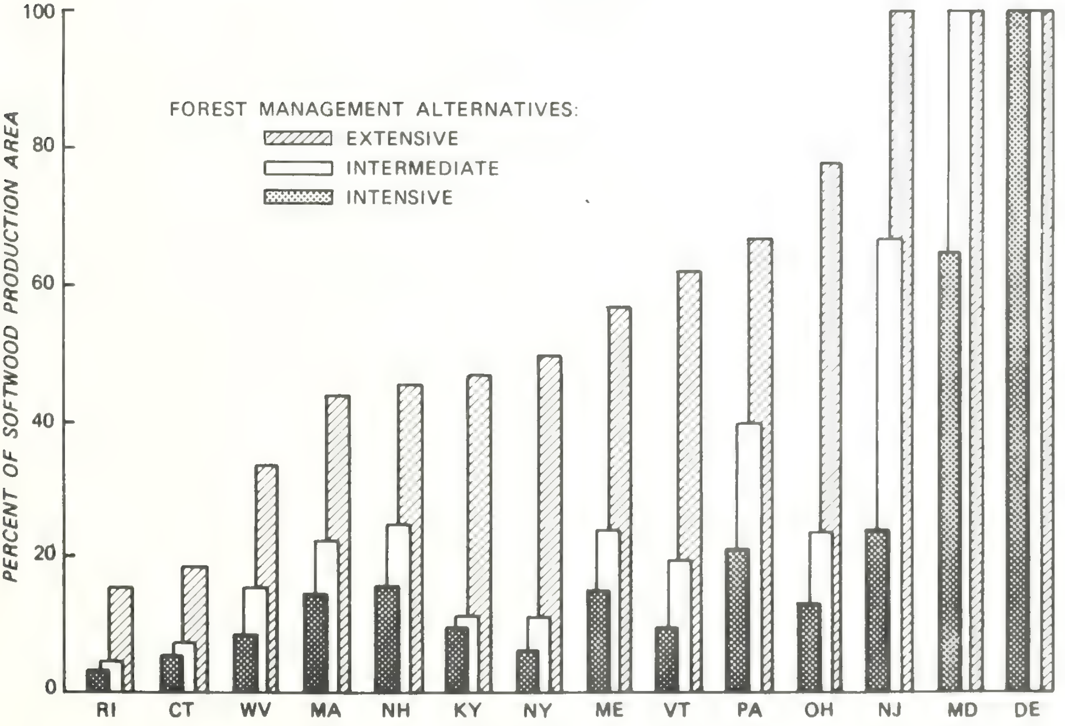
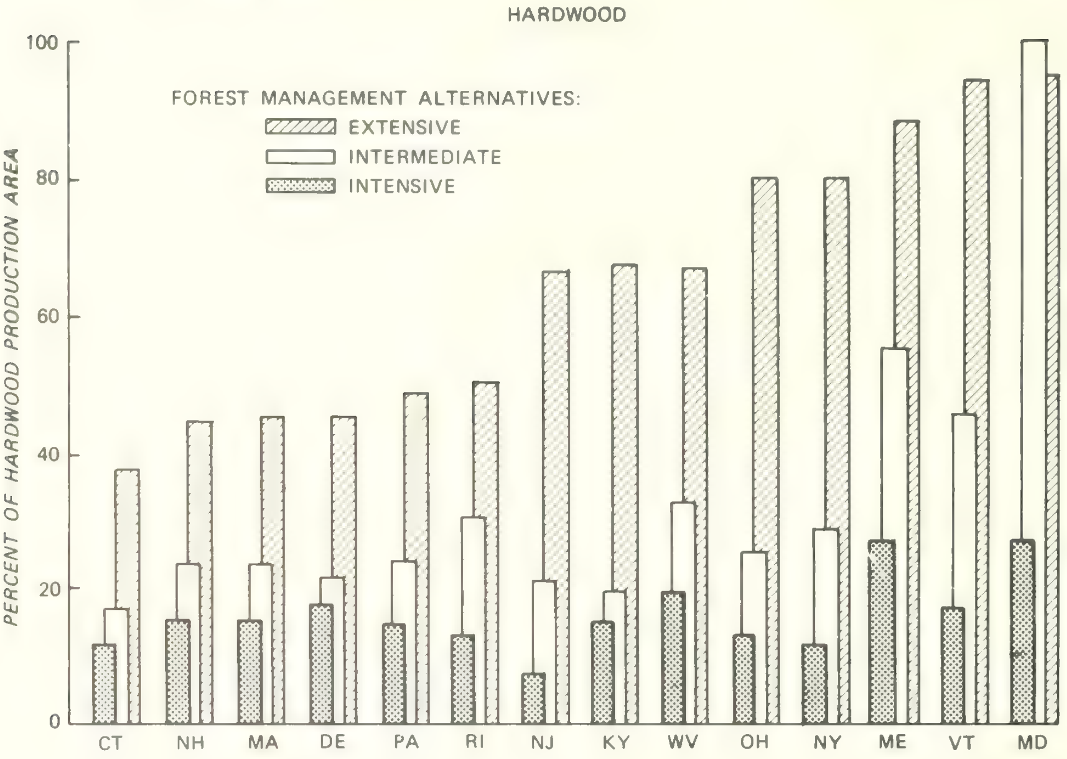
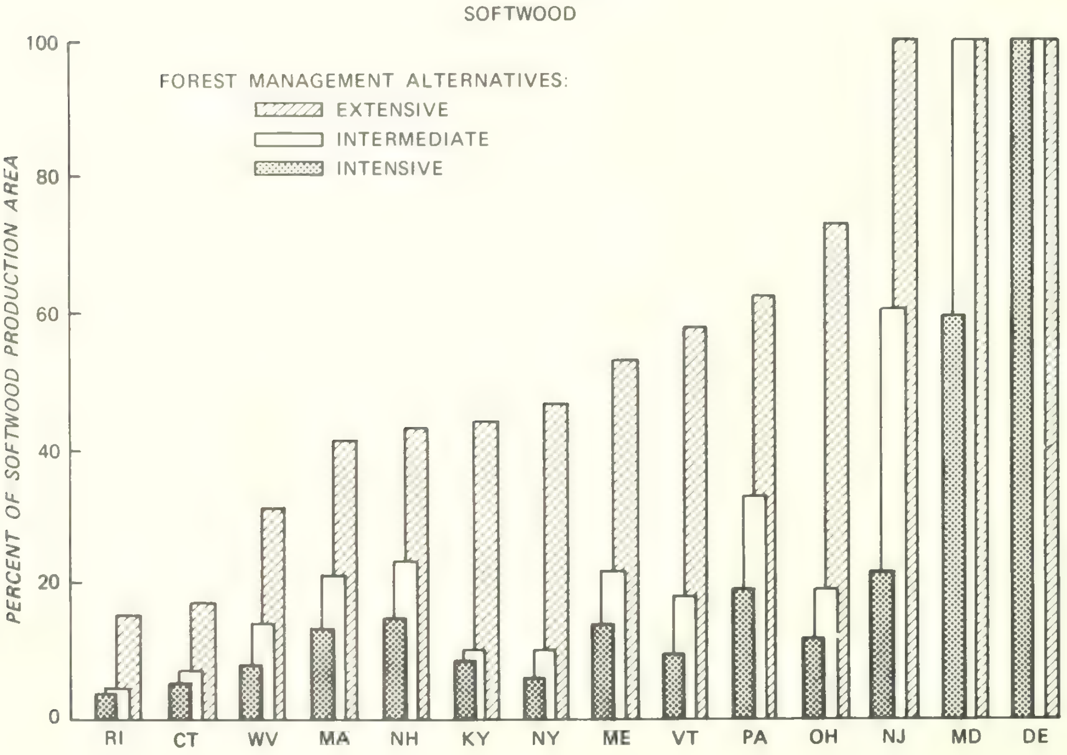


Figure 5.—Proportion of State's commercial forest area needed to meet timber demands projected at rising relative prices, for year 2000.





up the softwood deficit to prevent depletion of forest resources in those two states.

Intermediate management. The intermediate alternative for forest management and harvest also would satisfy most of the high-level projected demand for wood fiber in the year 2000. However, because it maintains the present acreage distribution among mean annual growth classes, intermediate management would require nearly twice as much forest area as intensive management. The gaps between sustainable timber production and projected demand for softwood in Delaware and Maryland and for hardwood in Maryland would have to be filled elsewhere in the region.

Low-level demand

At the opposite extreme of future timber requirements are the low-level projections of demand based on a continuation of recent timber removals per capita.

Extensive management. If current cutting practices continued, most northeastern states would have no trouble meeting these low-level estimates of roundwood consumption for the year 2000 (Fig. 4). Of course, since recent softwood timber removal has exceeded growth in Delaware, Maryland, and New Jersey, a continuation of current cutting practices would further deplete their softwood forest resources. In the rest of the region, low-level softwood demands could be met with slightly over half of the softwood commercial forest area. Thus depletion pressures on these three coastal states could be relieved elsewhere in the region.

Intensive management. With low demand and intensive management, the region's timber requirements in the year 2000 could be met with less than 15 percent of the hardwood area and 15 percent of the softwood production area. The only excess demand in the region would be for softwood in Delaware.

Intermediate-level demand

Between projections based on continued 1970 relative prices and those based on continued per capita consumption are the intermediate projections of roundwood requirements. These interact with the management alternatives in much the same way as the low-level (1970 per capita) projections (Fig. 5), but would require 20 to 30 percent more hardwood acreage and about 5 percent less softwood acreage to satisfy the projected roundwood consumption in the year 2000. The reduction in softwood acreage reflects underlying assumptions that cause lower estimates of softwood demand with rising relative prices than with stable per capita consumption of wood (see Figure 2).

INTRA-REGIONAL CAPABILITIES

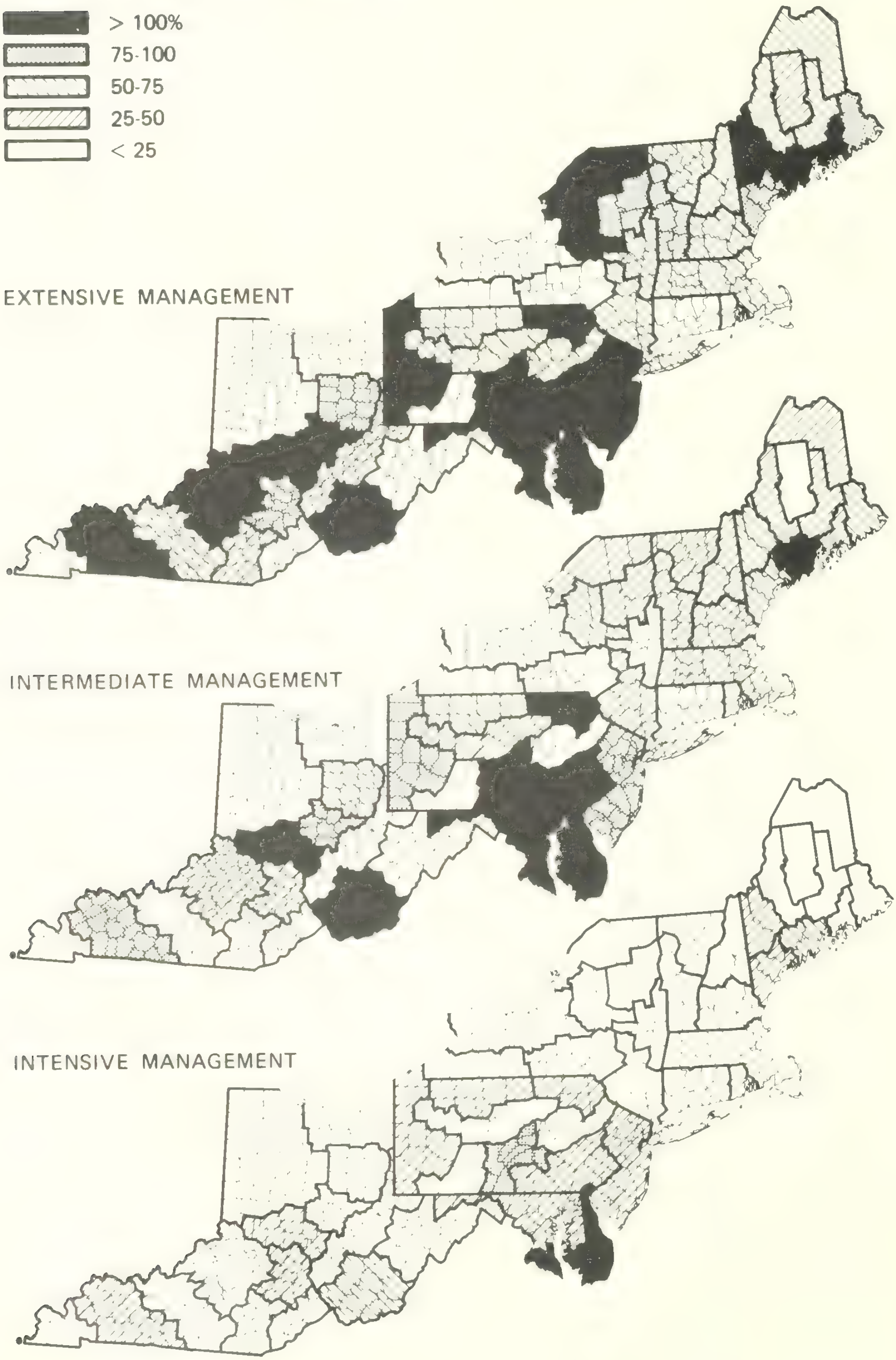
Certain combinations of timber demand and management intensity, such as low demand and intensive management, may not be very plausible. However, they help form a range of baseline projections or best estimates of maximal and minimal area requirements for wood production across the Northeast. Insofar as these baseline projections portray future conditions, they can serve as indicators of potential problems in an area and provide bases for corrective policies.

Further subdivision, from region to state to forest survey unit, accents the relatively less flexible nature of the smaller areas. Within the region as a whole there is plenty of leeway for adjusting to pressures that demands for wood fiber place upon the forest resource. But potential problem areas within the regional timber supply system become more apparent as we focus on smaller areas. Even states that will have no difficulty fulfilling estimated future requirements for wood fiber may contain subareas that do. For example, despite adequate capacity statewide, high-estimate wood fiber requirements will encounter tight supply situations in several of Pennsylvania's forest survey units. The different capabilities for fulfilling timber requirements across the region have been summarized as maps depicting the commercial forest area allotted to timber growing under the various assumptions about timber demand and management intensity (Figs. 6-8).

There are few areas in the Northeast where potential shortages in timber production persist through all alternatives considered here. For hardwoods, southern Maryland, New York's eastern Adirondack area, central Maine, and sections of western Ohio and Kentucky are most sensitive to timber production pressures. The greatest pressure on softwood resources occurs in Delaware, Maryland, southern West Virginia, and south-central Pennsylvania. New Jersey,

Text continues on page 14.

Figure 6a.—Proportion of softwood production area needed to meet high softwood timber demands (projected at 1970 relative prices) in year 2000.



EXTENSIVE MANAGEMENT

INTERMEDIATE MANAGEMENT

INTENSIVE MANAGEMENT

Figure 6b.—Proportion of hardwood production area needed to meet high hardwood timber demands (projected at 1970 relative prices in year 2000.

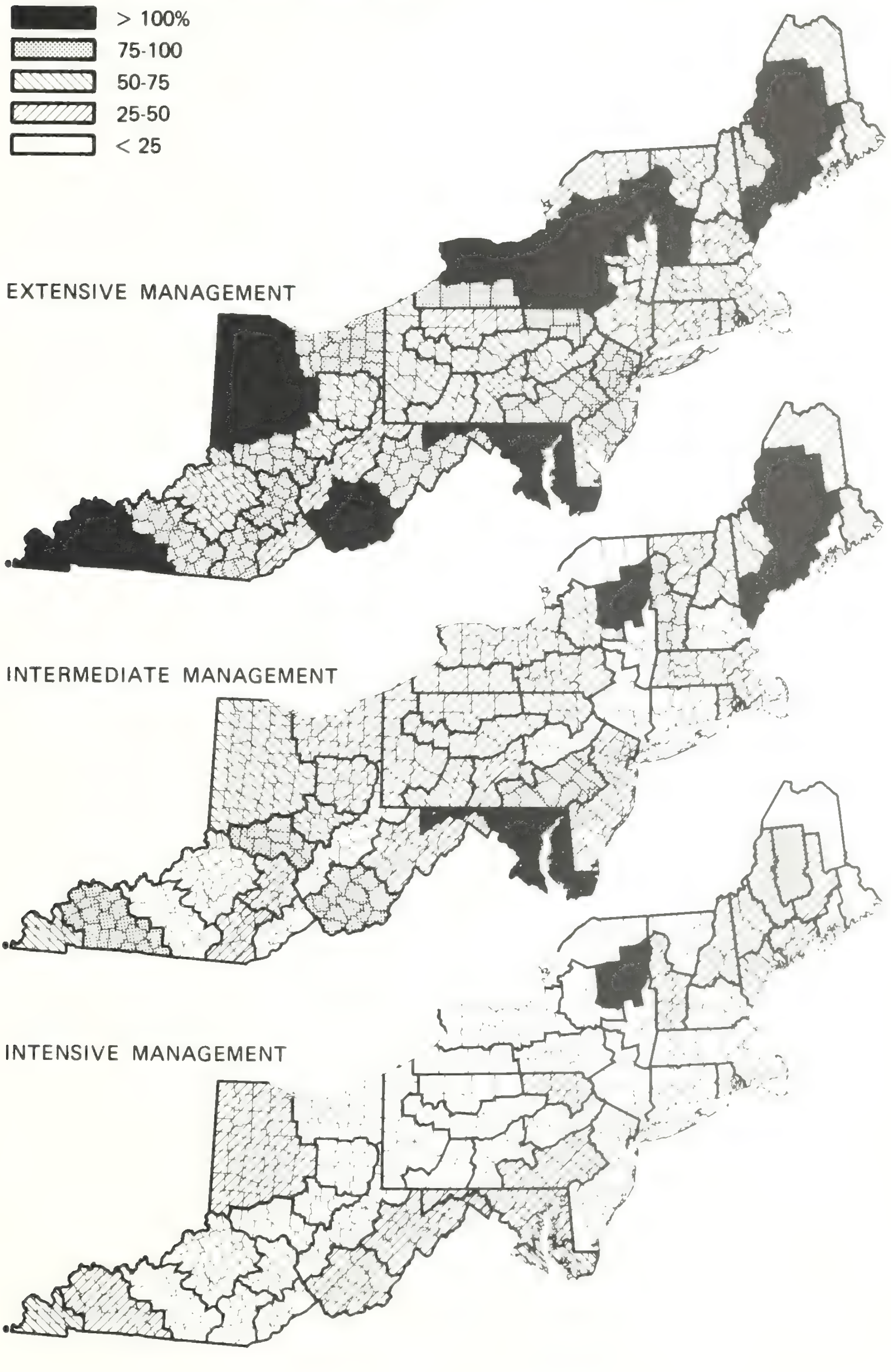


Figure 7a.—Proportion of softwood production area needed to meet intermediate softwood timber demands (projected at rising relative prices) in year 2000.

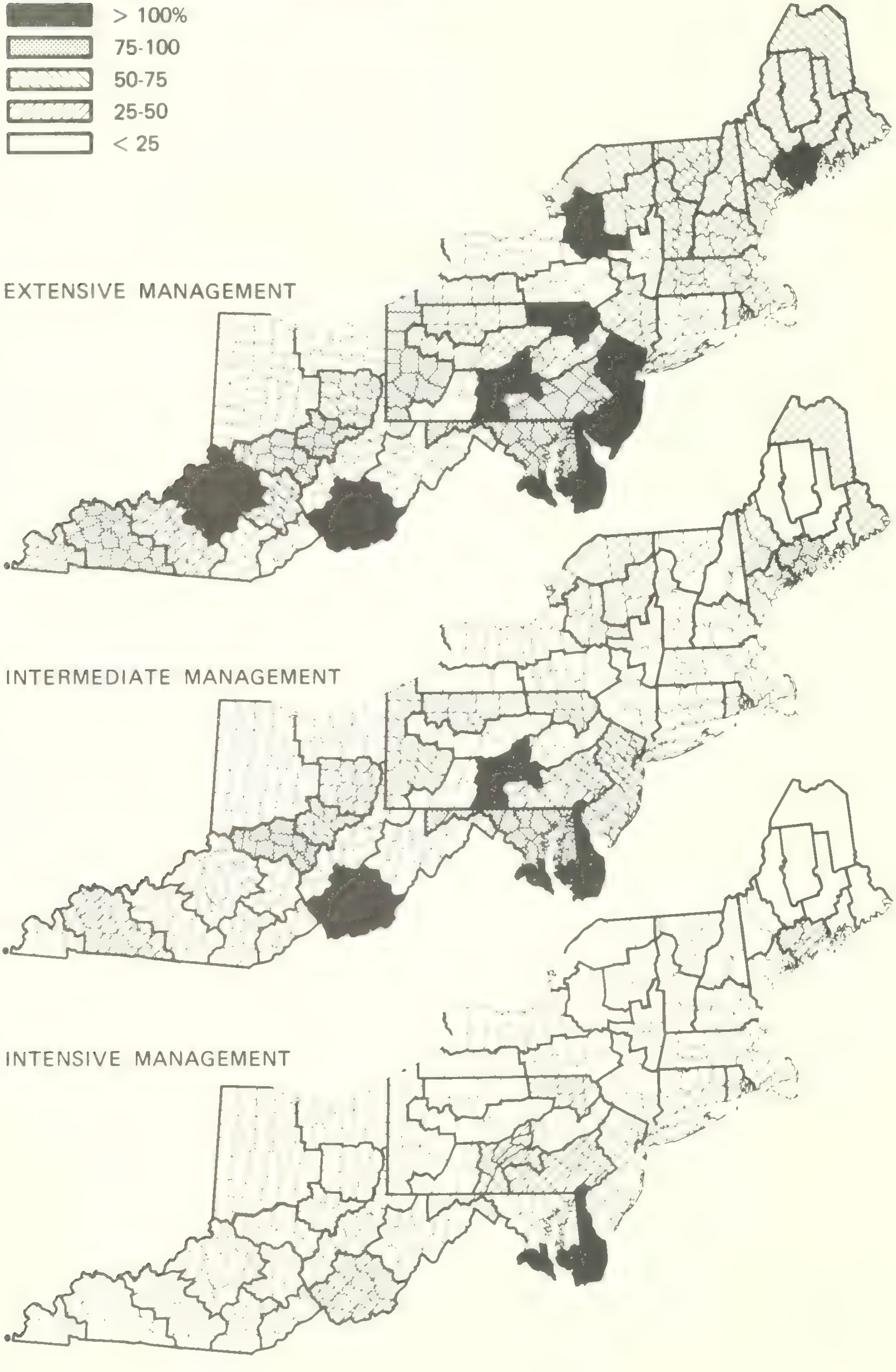


Figure 7b.—Proportion of hardwood production area needed to meet intermediate hardwood timber demands (projected at rising relative prices) in year 2000.

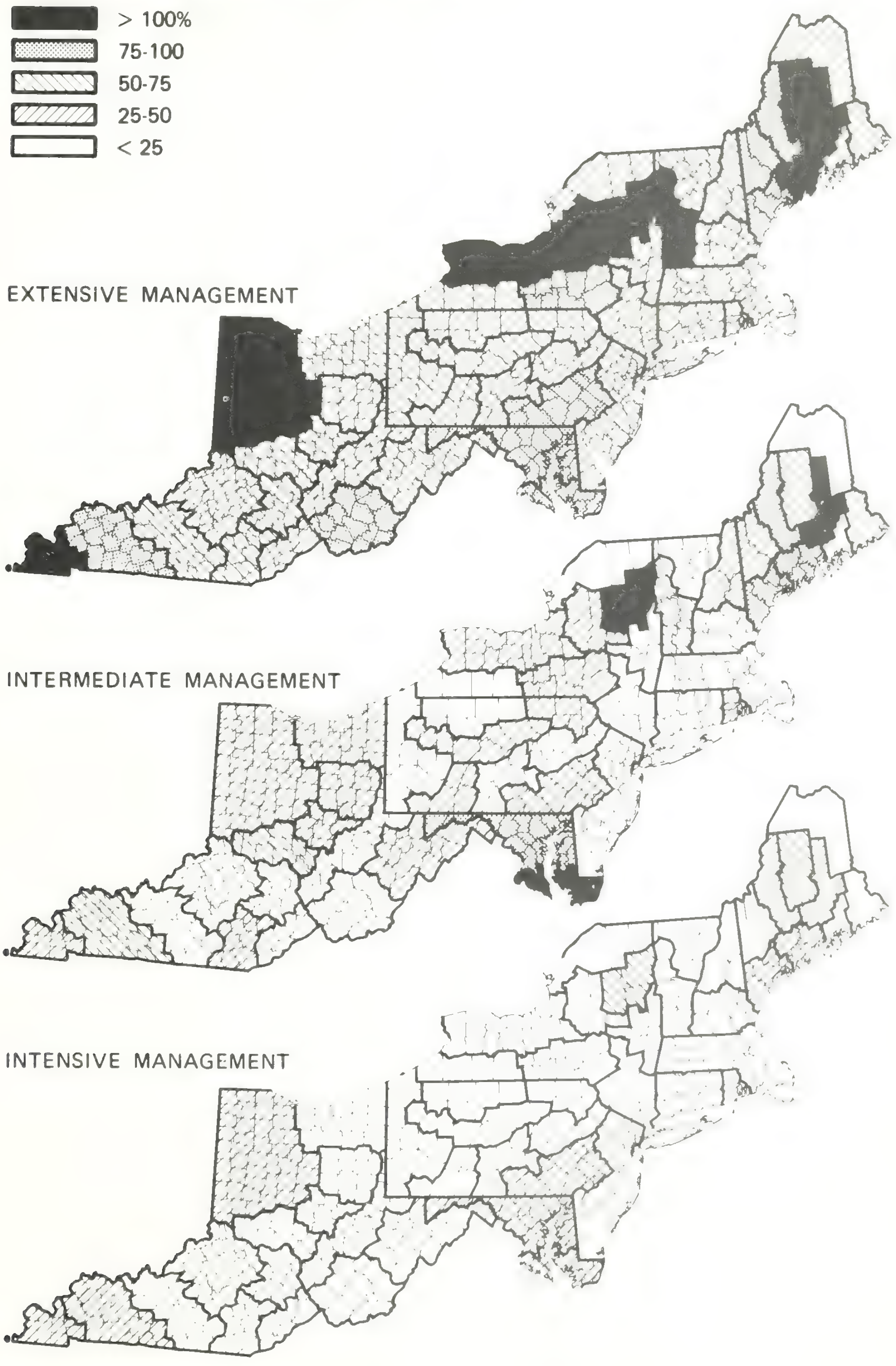
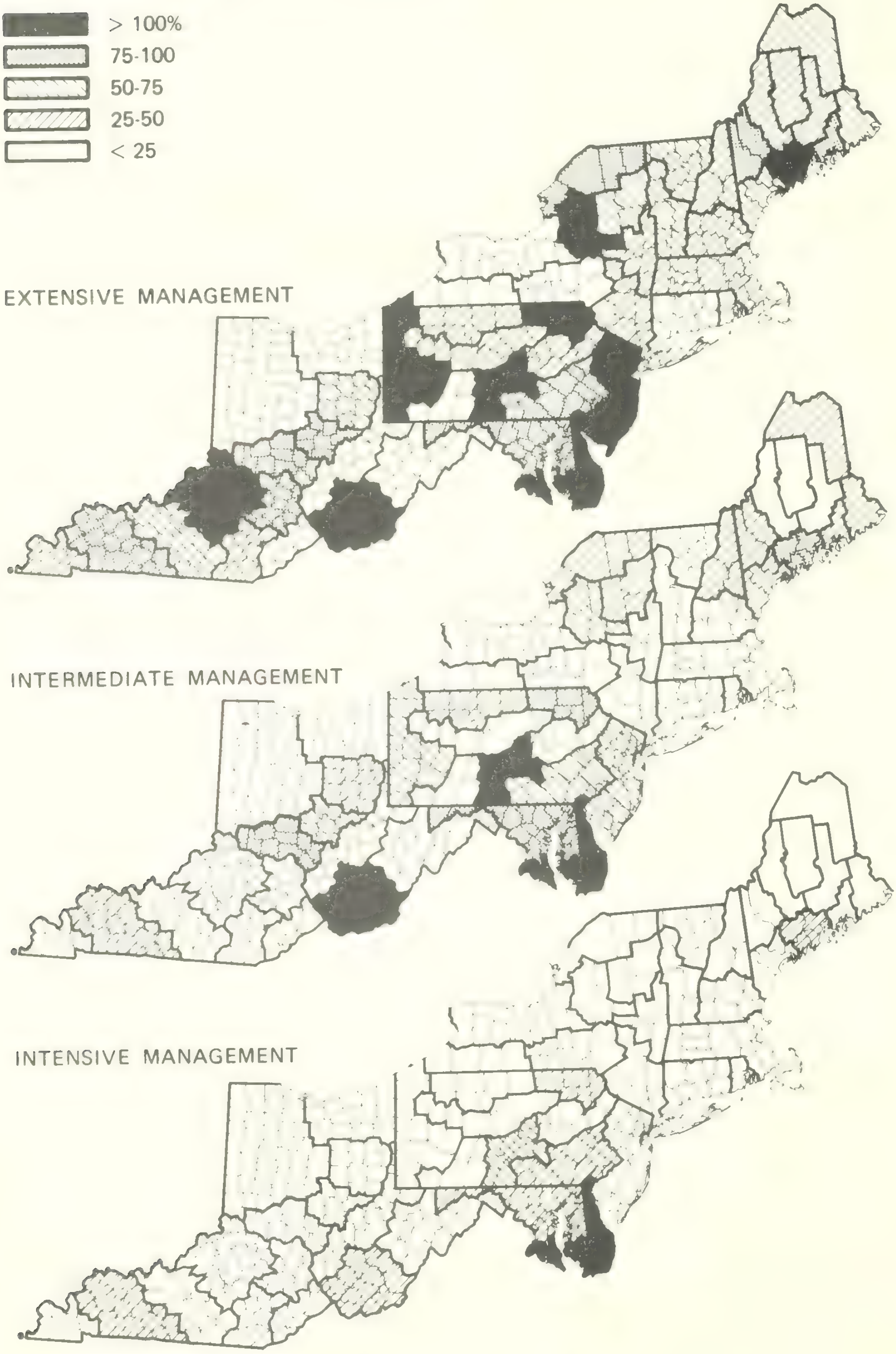


Figure 8a.—Proportion of softwood production area needed to meet low softwood timber demands (projected at current consumption per capita) in year 2000.

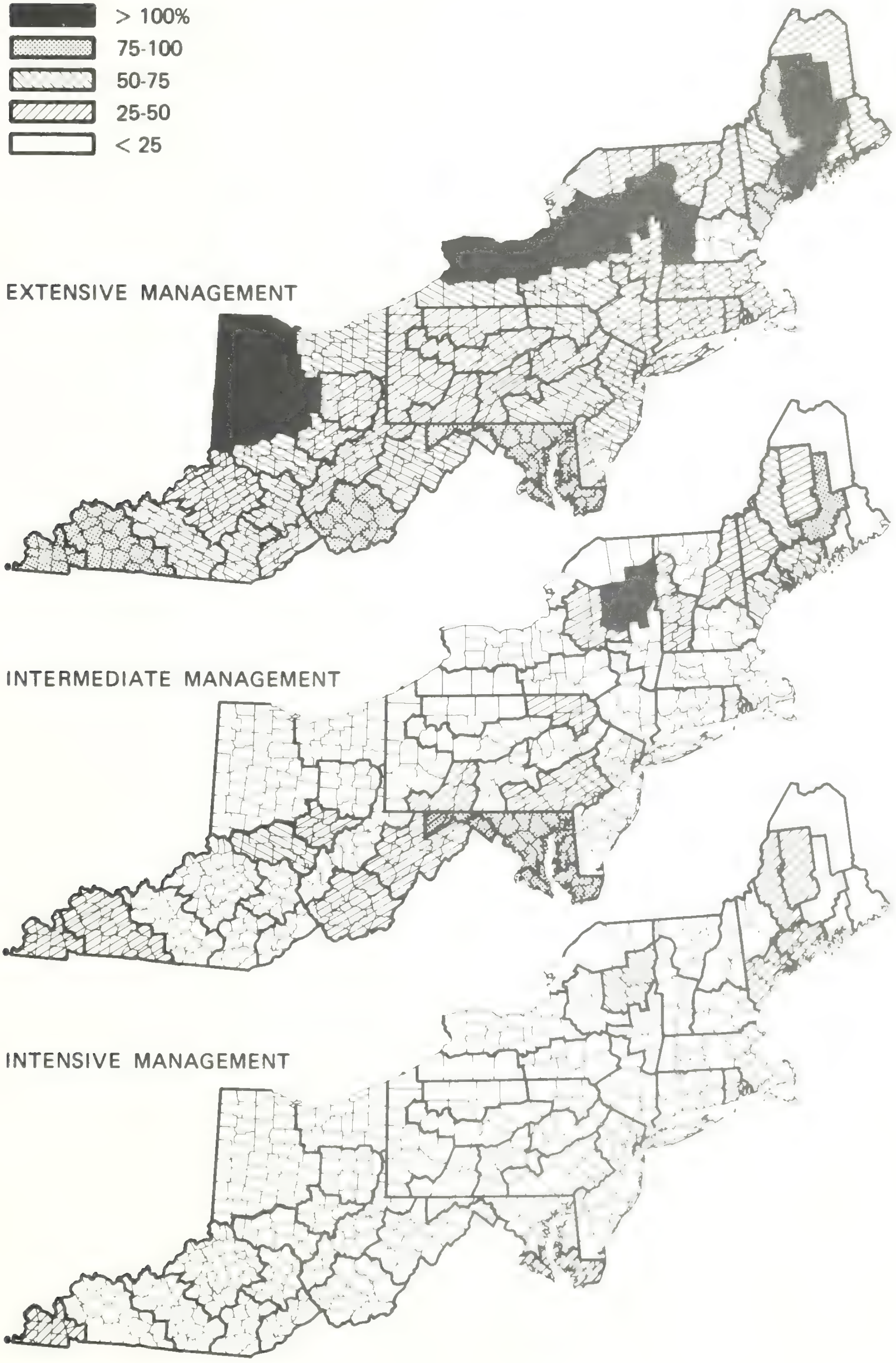


EXTENSIVE MANAGEMENT

INTERMEDIATE MANAGEMENT

INTENSIVE MANAGEMENT

Figure 8b.—Proportion of hardwood production area needed to meet low hardwood timber demands (projected at current consumption per capita) in year 2000.



northeast and western Pennsylvania, New York's western Adirondack area, south-central Maine, and north-central Kentucky will face deficit softwood resource problems if current practices continue as in the extensive management option. Within the Northeastern U.S., these areas are likely to be impacted most by further shifts toward the use of forest land for purposes other than timber growing.

CONCLUDING CONSIDERATIONS

Projections of the forest area needed for timber production that are based on a continuation of extensive forest land management assume that 1970 levels of emphasis on multiple-use, environmental, and economic objectives will continue. Projections based on intensive levels of forest land management assume that timber production will get primary emphasis on all commercial forest area needed to meet timber requirements.

A comparison of projected area needs (Figs. 3, 4, or 5) indicates the tradeoffs in commitment of forest area associated with esthetic, watershed, other multiple-use, and environmental management objectives. Management of commercial forest land exclusively for timber production is limited by these objectives. Thus, on one hand, it may not be possible to reach the minimum forest area commitment indicated by the intensive management option. It becomes attainable only where owners manage their land exclusively for timber production.

On the other hand, the extensive management option reflects the commercial forest land base and the social, economic, and environmental management levels of 1970. Changes in the emphasis placed on these objectives would result in more restrictive timber management practices.

The implication is that any change in emphasis from the 1970 mix of objectives guiding forest land use would require the concentration of timber production on fewer acres than those shown for the extensive solution for the year 2000. But many of the pressures that create change also create opposition to exclusive use. Consequently, it appears that projected timber requirements could best be met by encouraging timber growing and timber harvest in forest areas that have the greatest comparative advantage for this use. In addition to improved efficiency, a move in this direction would create greater flexibility in the framework for forest land use decisions.

Perhaps our intermediate management option is not far off the mark in suggesting the forest area needed to meet projected timber requirements. This middle ground would seem to provide the flexibility for some owners to practice intensive timber management while others stress multiple-use objectives. Overall, this would produce less timber volume per acre than intensive management. Thus it would require more forest acreage to meet the projected timber requirements for the year 2000.

The important point is that by spreading the burden of timber growing over a larger forest acreage it is possible to accommodate both intensive management and multiple-use objectives where each is most applicable. Under intermediate-level forest management, projected timber requirements for the year 2000 could be met from roughly half the existing commercial forest area. Thus there is a comfortable margin for adjusting to perhaps even less intensive management, as well as to uses of forest land that are incompatible with timber growing and timber harvest.

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14 p., illus. (U.S. Dep. Agric. For. Serv. Res. Pap. NE-390)

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Inheritance of Budbreak and Correlation with Early Height Growth in White Spruce (Picea glauca) from New England

by Ronald C. Wilkinson

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ABSTRACT

Variation in budbreak date among 37 half-sib families of white spruce in a replicated one-parent progeny test plantation in southern Maine was only 5 days. Differences in the mean date of budbreak between years were greater than those between families, but the genetic correlation between date of budbreak in different years was .661. Heritability estimates ranged from.228 to .814, depending on the year and method of calculation. In each of 2 years, heritabilities estimated for family selection were higher than those for mass selection of individual trees in the plantation, but family selection for late budbreak would result in genetic gains of less than 1.5 days if more than the two latest families were selected. Selections for late budbreak and rapid early height growth were not compatible; genetic correlations between date of budbreak and height elongation for the same year were large and negative.

INTRODUCTION

LATE BUDBREAK (flushing) is an important selection criterion for genetic improvement of white spruce *(Picea glauca* (Moench) Voss) in the North Central and Northeastern United States and in Canada (Nienstaedt and King 1969; Nienstaedt and Teich 1972). Early spring frost damage to white spruce planted in the open is avoided or is greatly reduced in trees with late budbreak.

Budbreak depends on temperature and the genetic constitution of a tree; it is under strong genetic control in white spruce. Progeny tests of white spruce in Wisconsin yielded heritability estimates for date of budbreak ranging from 0.28 to 0.70 (Nienstaedt and Teich 1972). Yeatman and Venkatesh (1974) reported a heritability of 0.91 from observations of five mature white spruce and their half- and full-sib progenies growing in Ontario, Canada. Nienstaedt and King (1969) showed in clonal selections that late budbreak and fast growth are positively correlated, and that simultaneous selection for late budbreak and superior growth is possible.

Despite these encouraging results, there are questions that remain unanswered. First: Is flushing in white spruce from the Northeast United States under strong genetic control? Second: Can selection for late budbreak be effectively applied to ongoing improvement programs for white spruce in which initial selection has been based entirely on rapid growth?

I attempted to answer these questions by recording budbreak date and measuring early height growth of half-sib families of white spruce—a one-parent progeny test for a plus-tree selection program in the Northeast—that are growing in a replicated plantation in southern Maine.

MATERIALS AND METHODS

The progeny test plantation contained 37 half-sib families. The female parents were plus trees in Maine and New Hampshire selected for sustained rapid growth rate and good form by cooperators in the Northeast Spruce-Fir Tree Improvement Program. Seed was collected from the parent trees in 1967 or 1968, and was sown in the New Hampshire State Nursery in the fall of 1970.

The 3-0 seedlings were planted in the field in 1974; the plantation site was an open field. The study design was a randomized complete-block with 4-tree row plots in each of 10 blocks; trees were planted at 8- by 8-foot spacings.

Height growth, both total height and current year height elongation, was measured in the late summer or early fall of 1974, 1975, and 1976, the end of the fourth, fifth, and sixth growing seasons.

I recorded budbreak date for individual trees in the springs of 1975 and 1976. In each year the trees were observed (every other day) from the beginning of budbreak until the last tree in the plantation had flushed. The date of budbreak was defined as the day when buds in the uppermost branch whorl showed green needles under the cap of bud scales; data was recorded as the number of days after April 27—the day before the first tree flushed in 1976.

Each set of data was analyzed separately using a least-squares analysis with unequal subclass numbers for plot means (Harvey 1960), and an analysis of variance for individual-tree values. Family and error variance components were estimated from the mean square for all variables.

Genetic, phenotypic, and environmental correlations between date of budbreak and height growth were obtained from cross-product analysis (Falconer 1960).

To estimate the effectiveness of selection for budbreak date and early height growth, two heritabilities were calculated from each analysis of variance. The first, or individual-tree heritability, is appropriate for estimating gain from mass selection among randomly placed seedlings in small test plantings. For the plot mean analysis, heritability was estimated using methods by Kriebel and others (1972):

$$h_i^2 = \frac{4\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + \hat{\sigma}_p^2 + \hat{\sigma}_w^2}$$

where:

$\hat{\sigma}_f^2$ = family variance

$\hat{\sigma}_p^2$ = plot error variance

$\hat{\sigma}_w^2$ = within-plot error variance.

For the individual-tree analysis, heritability was estimated by:

$$h_i^2 = \frac{4\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + \hat{\sigma}_e^2}$$

where:

$\hat{\sigma}_f^2$ = family variance

$\hat{\sigma}_e^2$ = error variance.

The second, or family heritability, is appropriate for estimating gain from selection among half-sib families if 4 seedlings per plot and 10 replicates of each family plot are used to judge the potential of each family. For the plot mean analysis, heritability was estimated by:

$$h_f^2 = \frac{\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + 10^{-1}\hat{\sigma}_p^2 + 40^{-1}\hat{\sigma}_w^2}$$

For the individual-tree analysis family heritability was estimated by:

$$h_f^2 = \frac{\hat{\sigma}_f^2}{\hat{\sigma}_f^2 + 40^{-1}\hat{\sigma}_e^2}$$

RESULTS AND DISCUSSION

Differences in budbreak among white spruce of as many as 21 days were reported by Nienstaedt and Teich (1972); this figure is near the range of variation for the seedling material in this study. The range of budbreak in family means was quite small (Table 1). In 1975, the earliest and latest families differed by less than 4 days; in 1976, the difference was only 5 days. Differences between individual trees were greater than those between families, 12 days in 1975, and 19 days in 1976.

Differences in mean budbreak between 1975 and 1976 for both families and individual trees

Table 1.—*Overall mean and ranges for date of budbreak of half-sib families and individual trees in 1975 and 1976*

Budbreak year	Mean [a]	Range	
		Individuals	Family means
		Days	
1975	23.1	12	3.5
1976	8.3	19	5.1

[a] Days from April 27 in each year.

are almost entirely functions of early spring temperature. Differences in budbreak of up to 2 weeks from year to year are normal (Nienstaedt and King 1969). In 1976, an unusually warm period in early April—including a week with daytime temperatures in the high 90's—was responsible for budbreak as early as April 28; in 1975, the earliest individual trees did not break bud until May 16.

Heritability estimates for date of budbreak ranged from .228 to .814, depending on the year and the method of calculation (Table 2); the estimates for date of budbreak were somewhat higher in 1976 than in 1975. In both years, heritabilities for family selection were higher than those for mass selection of individual trees.

Heritability estimates for total height were high; they approached or were greater than 1.0 in 1974, 1975, and 1976. However these values are not reported here because they would be useless in predicting response to selection. Overestimates of heritability for early height growth in half-sib progeny tests are common. The assumption that all progeny within families are half-sibs and that differences between families account for only 1/4 of the additive genetic variance may be one source of overestimation. Another could be the presence of maternal effects.

Heritability estimates for height elongation decreased with age; the tendency for heritability to decrease with age has been noted in many species. The high heritability in 1974 may have been caused by the uniformity of growth in all trees in the first year after transplanting. In 1975 and 1976, heritability estimates for height elongation were approximately equal to or slightly lower than those for budbreak.

My heritability estimates for flushing are close to those of Nienstaedt and King (1969), but they are lower than 0.91 reported by Yeatman and Venkatesh (1974). The estimates by Nienstaedt and King were derived from controlled-cross progeny of parent material selected for extreme differences in date of budbreak. My estimates are probably more conservative, and probably would have been higher had there been a wider array of genotypes in the plantation.

The heritability estimates are large enough to permit effective selection for late budbreak, but selection in the progeny test plantation would not be effective because of the lack of variation. Family selection at any intensity greater than 5 percent, even with a high heritability, would result in gains of less than 1.5 days. Individual-tree selection, despite a lower heritability, is slightly more promising; but selecting those trees that flushed on the last day in each year would result in an average gain of only 3.9 days. Even if such intense selection were possible, this gain would not be significant in avoiding frost.

Date of flushing is influenced by juvenility, and flushing is progressively later with advancing age (Nienstaedt and King 1969). So it is possible that the differential between families would become greater, and that opportunities for selection at an advanced age would improve.

Table 2.—*Heritability estimates for date of budbreak and early height growth of half-sib progenies of white spruce*

Growth character and year	Plot mean analysis		Individual tree analysis	
	Individual heritability	Family heritability	Individual heritability	Family heritability
Budbreak				
1975	.420 ± .206	.647	.228	.708
1976	.461 ± .212	.652	.396	.814
Height elongation				
1974	1.153 ± .285	.867	.811	.911
1975	.395 ± .198	.604	.241	.720
1976	.280 ± .178	.507	.296	.762

Additional measurements of flushing date in this plantation will be made to investigate this possibility.

The phenotypic correlation between date of budbreak in 1975 and that in 1976 was close to zero, but the genetic correlation of .661 is significantly positive. This uniform family response to different environmental conditions is further evidence of the strong genetic control of budbreak in white spruce. The ranking of families for budbreak date changed little from one year to the next, while the ranking of individual trees fluctuated from year to year. The family that had the second latest budbreak date in 1975 had the latest budbreak in 1976, and the earliest family in 1975 was the second earliest in 1976. In all, 25 families changed less than 10 positions in ranking from one year to the next, and 14 of these families changed less than 5 positions. The strong positive genetic correlation between budbreak dates in 1975 and 1976 is somewhat surprising when the range of only 5 days between all families is considered.

Selection for late budbreak in this plantation would be selection against rapid height growth. Correlations between date of budbreak and height growth in both years were low or were negative (Table 3); correlations between date of budbreak and height elongation were close to zero or were negative. More importantly, for simultaneous selection, the genetic correlations between date of budbreak and height elongation for the same year are large and negative, especially in 1976. Overall, the correlation between budbreak and height growth was more strongly negative in 1976 than in 1975.

These negative correlations do not agree with the findings of Nienstaedt and King (1969), who reported a correlation of .605 between flushing and mean height growth; they also found that late flushing clones were 42 percent taller than early flushing clones. However the correlations between flushing and height growth were negative in progenies from several of these clones (Nienstaedt 1972).

There may be an explanation for the negative correlations that I obtained. If it is assumed that late budbreak and rapid growth are positively correlated, then the initial selection of parents for rapid growth may have resulted in the concurrent selection for late budbreak. All of the families in the progeny test would be late flushing, explaining the lack of variation in flushing date, and all of the correlations would

Table 3.—*Phenotypic, genetic, and environmental correlation coefficients between date of budbreak and early height growth of half-sib progenies of white spruce*

Budbreak year [a]	Growth character and year	Phenotypic correlation r	Genetic correlation r	Environmental correlation r
1975	*Height elongation*			
	1974	−.073	.093	−.238
	1975	−.363	−.688	−.060
	Total height			
	1974	.103	.157	.028
	1975	−.010	−.084	.131
1976	*Height elongation*			
	1975	−.063	−.523	.456
	1976	−.272	−.943	.300
	Total height			
	1975	−.056	−.206	.279
	1976	−.164	−.410	.624

[a] Correlation coefficients between budbreak date in 1975 and in 1976 are .071, .661, and −.440 for phenotypic, genetic, and environmental correlations, respectively.

be within a small, select group. Nienstaedt and King (1969) found that within-group relations between flushing and clonal elongation and mean growth rate were unclear, and, in some instances, they were negatively correlated.

At this stage it would be difficult to establish whether the negative correlation between height growth and budbreak date applies generally to white spruce as a species, or whether the correlations represent only a within-sample relationship. However the simple correlation for date of budbreak and height growth rate for all of the individual trees in the plantation for both years was .053, or no correlation. And these trees varied by almost 20 days in date of budbreak. Also, the correlation between budbreak date and height growth elongation was negative in 32 of the 37 families in 1975, and in 26 families in 1976.

This relationship between budbreak date and height growth rate in white spruce may require further clarification. Until then, I believe that a negative or no correlation between these two traits in seedling material should be assumed for selection in improvement programs where initial selection has been based exclusively on growth rate.

CONCLUSIONS

Although the strong genetic control of budbreak date in white spruce was confirmed, high heritabilities were not sufficient to ensure adequate genetic gains from a selection program. Selection for late budbreak in progeny test plantations where initial parental selections were made only for rapid growth rate may not be successful due to lack of variation and low selection differentials. The low selection differential coupled with the negative correlation between budbreak date and height growth rate suggest that these two traits be considered mutually exclusive, and that any improvement programs in the Northeast should be for only one trait or the other. The choice would depend on the general and local climates at the proposed planting sites, and on whether frost avoidance or rapid height growth rate is more important in those climates.

Finally, the early budbreak pattern in 1976—due to unseasonable spring temperatures—suggests that in some years, even the latest flushing genotypes might suffer considerable frost damage in southern New England, where it is considered extremely risky to plant a vegetable garden before the last day of May.

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Natural Reforestation Reclaims a Watershed:

A Case History from West Virginia

by W. P. Lima, J. H. Patric,
and N. Holowaychuk

FOREST SERVICE RESEARCH PAPER NE-392
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ABSTRACT

Thirteen years of hydrologic data from two contiguous small watersheds in West Virginia were analyzed to determine the effects on streamflow of natural reforestation on abandoned farmlands. During the study period (1958-1970), streamflow on the watersheds was unchanged. The history of land use on the study area helps explain the apparent lack of hydrologic effects of reforestation. Aerial photographs taken in 1933, 1945, 1956, and 1968 documented the rapid advance of reforestation. Observations of streamflow began about 25 years after farming had terminated; any measurable hydrologic effects of natural reforestation probably occurred before these observations.

SUCCESSIVE STAGES of exploitation of indigenous resources—wildlife, plant cover, soil, and water—usually occur when land is occupied by agrarian people. This progressively intensive exploitation always results in the modification of the original environment—and often in the deterioration of the indigenous resources. The exploitation of resources, unless it was drastic, tended to be self-terminating in the Appalachian region of the United States. Where the terrain was steep, the destruction of forest vegetation soon caused soil erosion and stream siltation. In time, human occupancy waned, so the land was subjected to less demanding use, and it reverted to natural forest.

Two small watersheds near Parsons, West Virginia, provide an example of this sequence. Our report examines changes caused by exploitive land use, the natural revegetation that followed, and their interacting effects on watersheds.

THE STUDY AREA

The watersheds, designated Clover Watershed 8 and 9, are within the Monongahela National Forest, about 15 km northwest of Parsons, in Tucker County, West Virginia (Fig. 1). They are contiguous headwater branches of Clover Run, a small tributary of the Cheat River that is part of the Ohio River system. Strong relief and steep terrain characterize the study area. Watershed 9 is somewhat less steep than Watershed 8 (Table 1), but most of the study area has slopes of 30 percent or greater. Today, such land is considered unsuitable for cultivation because the steep soils are easily eroded (U.S. Soil Conserv. Serv. 1970).

Nearly all of the study area is underlain with alternating strata of Devonian shales and sandstones of the Hampshire and Chemung series. Small patches of a Mississippian

Figure 1.—Watersheds 8 and 9 in Tucker County, West Virginia.

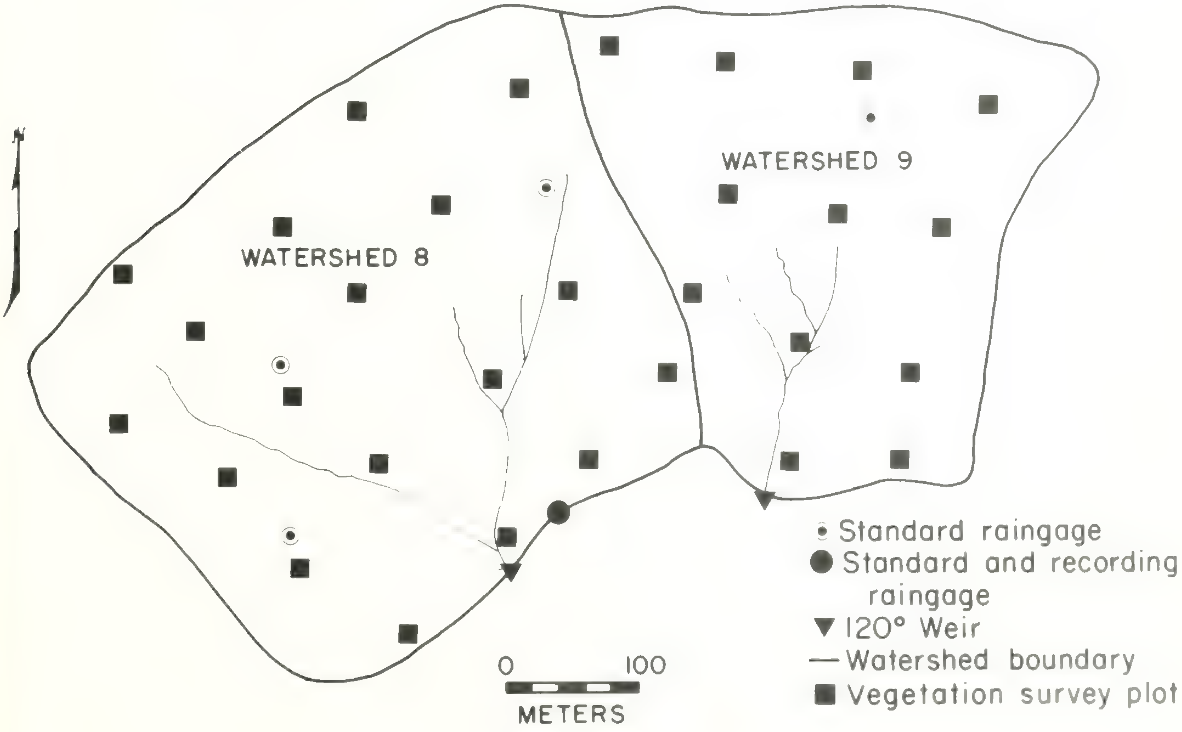


Table 1.—Physical characteristics of the Clover watersheds

Characteristic	Watershed 8	Watershed 9
Area (ha)	19.1	11.6
Relief (m)	147	85
Mean elevation (m)	795	784
Percent of land in:		
10 - 20% slopes	16	45
30 - 40% slopes	56	48
40 - 75% slopes	28	7

sandstone (Pocono series) occur on higher portions of the divides (Reger 1923).

Climate

The climate of the study area is humid-temperate; the seasonal distribution of precipitation is fairly even. The relief and the striking differences in elevation, however, influence both temperature and precipitation (Losche and Beverage 1967). At Parsons (elevation: 515 m), the mean annual precipitation and temperature are 1,120 mm and 17.8°C, respectively; at Canaan in Tucker County (elevation: 970 m), these values are 1,360 mm and 14.4°C. The influence of elevation is reflected in the annual frost-free period; the average frost-free period is 150 days at Parsons and 90 days at Canaan.

Snowfall is common; 10 years of data indicate a yearly average of 37 and 70 days with snow cover at Parsons and Canaan, respectively. Losche and Beverage (1967) stated that "Rainfall . . . is adequate for the needs of most crops . . . Rainfall heavy enough to cause local floods occurs occasionally, usually accompanying a thunderstorm. Totals of more than 5 inches (127 mm) in a 24-hour period have been recorded."

Weather information was recorded on the study watersheds from 1958 to 1970. These data (Lima 1971) show a mean annual precipitation of 1,480 mm distributed evenly throughout the year. The mean temperature was −4.0°C for January, 18.9°C for July, and 8.4°C for the entire year. These data differ little from those for the other stations in the Central Climatological Division of West Virginia (U.S. Environ. Data Serv. 1958-1970). The calculated potential evapotranspiration (Black 1967) averaged 609 mm per year; there was no season of soil moisture deficit.

Soils

The watershed soils are acid, moderately thick, and medium textured. They have formed in materials derived from the shale and sandstone bedrock; the bedrock is usually within 0.6 to 1.2 m of the surface. Rock fragments are common in the subsoil and they are especially abundant in Dekalb soil. All of the watershed soils are moderately permeable, low to moderate in fertility. The soils include 3 series—Calvin, Dekalb, and Gilpin—of which Calvin is the most extensive.

The Calvin and Dekalb series are classified as Typic Dystrochrepts, loamy skeletal, mixed mesic; the Gilpin series as Typic Hapluudults, fine loamy, mixed mesic (U.S. Soil Conserv. Serv. 1972). These soils series are given the hydrologic classification of "C". Soils in this classification are those "having slow infiltration rates when thoroughly wetted. They consist chiefly of soils with a layer that impedes downward movement of water, soils with moderately fine to fine texture, or soils with moderately high water tables" (U.S. Soil Conserv. Serv. 1970). The presence of bedrock, especially shale, impedes the downward movement of water, even though these soils are moderately permeable.

There is considerable evidence of severe erosion on about 90 percent of the area (Losche and Beverage 1967). A few small patches of soil are still eroding, and there are stable accumulations of sediment along streams, healed gullies, and plow lines. Natural revegetation has effectively halted erosion; gullies have been stabilized by grass, brush, and small trees. Most of the soil is now permeated with roots, and it has acquired appreciable organic matter, indicated by a dark brown or a dark grey color. The surface soil is somewhat granular and absorbs rain readily.

Land use

The first recorded settlement on Clover Run was a cabin built in 1836 (Maxwell 1884). The population must have increased rapidly because Clover Run became a voting district in 1876; by 1900, Clover Run boasted schools, churches, a store, and a post office (Fansler 1962).

The history of land use on the Clover watersheds begins with Maxwell's (1884) description of farms owned by the Phillips brothers; one farm was 59 ha with 16 ha improved, the other was 32 ha with 14 ha improved. A portion of the larger farm became Watershed 8, and a portion of the smaller became Watershed 9. Wade Phillips, a son of one of the pioneer owners, still lives in Parsons. He once operated a portion of the original farm that now includes Watershed 9. His recollections outline a fairly detailed history of land use.

One of Mr. Phillips's earliest memories is of a primitive water-powered sawmill on his father's farm. The sawmill was later replaced by a steam-powered mill. Some of the lumber sawed at the older mill was used to add rooms to the original log house. Commercial logging probably began about 1890 because by 1910, only 1.4 ha of woodland remained on the farm.

During World War I, Mr. Phillips farmed about 16 ha; more than half of this land provided hay and pasture for livestock. The remainder, cropped with a rotation of corn, oats, and buckwheat, provided adequately for a family of five children. For about the first two decades of this century, the Clover Run District was considered a prosperous farming community. But despite the conscientious use of then-current conservation practices, Mr. Phillips felt that the plowed fields had been subjected to serious erosion. The farm was sold to a Mr. Wilfong in 1920. An aerial photograph taken in 1933 indicates that once-cultivated fields were predominantly in grass; they also contained small trees and other pioneer vegetation. Apparently, this farm had been abandoned before 1930.

Phillips (1925) suggests that land use on the Clover watersheds must have been typical of agriculture throughout the vicinity:

> "The pioneers . . . were attracted by the level, well-drained bottoms, which they rapidly cleared and put in corn. For meat they depended chiefly upon game in the surrounding forests . . . Other crops, such as wheat and oats, were introduced but corn remained the chief cultivated crop. Gradually, the smaller valleys were settled and adjacent hill slopes were cleared. Much of the steeper land after a few years of cultivation failed to give profitable yields and was turned into pasture or allowed to grow up in brush . . ".

In 1941, the study area was purchased by the Forest Service from Mrs. Wilfong, then the absentee owner. Notes from the purchase documents (on file at the Ranger's Office, Cheat District, Monongahela National Forest) suggest that many sad events must have preceded the sale:

> "This was formerly a hill farm but has been abandoned for several years . . . All buildings are in very poor condition. A considerable area was at one time cleared but several of the fields are in various stages of restocking from brush, briers, and reproduction to pole size. Other fields more recently abandoned bear sedge and briers, in some instances sassafras and locust. It is doubtful if this farm will ever be reoccupied because of its location and worn-out fields and poor buildings."

After the land was purchased, natural revegetation continued without incident or interruption. In 1956, this area was selected for a study on how streamflow is influenced by natural reforestation of abandoned farmland. Two contiguous catchments—Watersheds 8 and 9—were deemed typical of much of the abandoned farmland in the central Appalachian region. Soil and vegetation were surveyed, and measurements of precipitation, streamflow, temperature, and humidity began on November 1, 1957. The use of these records to interpret watershed behavior was described at length by Reinhart et al. (1963).

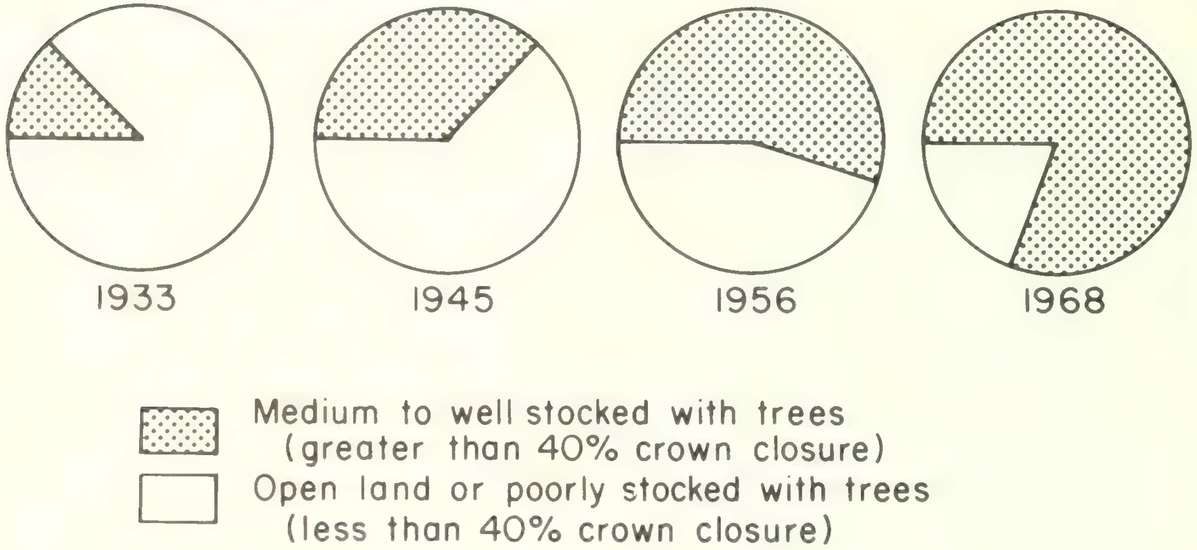
Similar agricultural use of hill country extended far beyond this small area of West Virginia. In fact, during the Depression, problems stemming from such use were endemic to much mountain land in the Eastern United States (Barnes 1938). Thus natural reversion of the Clover watersheds to forest is relevent to current environmental concern throughout the Appalachian region.

Changes in vegetation

The old-growth vegetative cover was lush oak-chestnut forest; there also were white pine and considerable eastern hemlock. Little is known of early changes in vegetation after initial settlement. No doubt the more desirable and accessible trees were harvested first; this was followed by more extensive logging and, later still, by clearing for farm land.

An aerial photograph of the watersheds taken in 1933 shows many newly abandoned fields, most of them with hedgerows, and some containing isolated small trees and brush patches. Aerial photographs taken in 1945, 1956, and

Figure 2.—Changes in tree and brush cover and in open space from 1933 to 1968 on Watersheds 8 and 9.



1968 show expanding tree and brush cover and a corresponding decrease in open land. Measurements of this tree and brush cover by photo interpretation (Fig. 2) indicate that this natural reforestation covered about 80 percent of the watershed areas by 1968.

In addition to the photographic record, ground surveys of the vegetation were made, one in 1959 and the other in 1971. These surveys, based on plot inventories (Fig. 1), showed that the open areas were largely in grass, and that tree and brush stands contained a wide range of species. The number and relative abundance of tree species larger than 2.5 cm in diameter at breast height (dbh) indicate that a profusion of species had invaded the watersheds quickly (Table 2).

Hydrology

The first 8 years (1958-1965) of streamflow data showed a slight but statistically nonsignificant decrease in water yield (Hornbeck and Troendle 1969). Lima (1971) reached the same conclusion after analyzing 13 years (1958-1971) of streamflow data. Flow decrease for the entire period was 86 mm for Watershed 8, 30 mm for Watershed 9. Multiple regression analysis also showed a consistent but statistically nonsignificant relationship of natural revegetation to reduced streamflow. As reforestation progressed, the soil was depleted of moisture to progressively greater depths, and greater precipitation was required to replenish the soils before water became available for streamflow.

Specific conductance, pH, methyl orange alkalinity, turbidity, and temperature were measured routinely during the observation period. During most of this period, the turbidity of streams draining the Clover watersheds (Table 3) was near the 5 JTU (Jackson Turbidity Unit) ceiling established for drinking water (U.S. Public Health Serv. 1962). Maximum turbidity (from a June thunderstorm) was only slightly higher than turbidity in a stream draining a nearby watershed forested with old-growth hardwood. These measurements provide a subtle yardstick of environmental quality. Streams draining the Clover watersheds differed little in quality from the stream on undisturbed forest land.

DISCUSSION

Aerial photography and ground surveys present indisputable evidence of slow but persistent reforestation. Not only is an adequate forest developing, but the area probably is near a peak of wildlife productivity. As Larson (1967) stated: "It was soon realized that optimum forest game habitat existed at a point somewhere in the middle of the area between bare land and climax forest." Neither completely clear nor forested,

Table 2.—Relative abundance of trees more than 2.5 cm in dbh on Clover watersheds; data from vegetation survey plots

Species	Watershed 8		Watershed 9	
	1959	1971	1959	1971
	Percent of basal area			
Apple	1	p[a]	1	p
White ash	4	3	11	2
Bigtooth aspen	--	-[b]	2	--
Quaking aspen	--	p	--	--
American beech	--	1	1	p
Sweet birch	6	1	7	4
Black cherry	4	7	5	7
Cucumbertree	--	--	--	p
Dogwood	5	2	2	p
American elm	--	--	--	p
Shagbark hickory	20	16	8	12
Black locust	6	14	11	11
Red maple	11	17	8	12
Sugar maple	8	5	1	1
Chestnut oak	1	4	--	2
Northern red oak	6	5	3	5
Scarlet oak	--	--	--	p
White oak	3	2	1	3
Sassafras	15	10	15	26
Downy serviceberry	6	1	2	p
Sourwood	1	7	2	5
Staghorn sumac	--	p	p	p
Black tupelo	4	p	7	2
Witch hazel	p	1	p	p
Yellow-poplar	2	3	11	7
Species present (no.)	18	21	20	23
Basal area (m²/ha)	9.59	18.34	5.44	15.56

[a] Present in stands but not common.
[b] Not tallied on plots.

Table 3.—Water quality values for Clover watersheds, and for a nearby permanently forested watershed

Parameter	Long term mean		Maximum observed	
	Clover	Forested	Clover	Forested
Turbidity (JTU)	5	5	210	15
Temperature (°F)				
Average maximum	54.1	52.8	63.5	61.8
Average minimum	43.3	43.3	34.6	35.0
pH	5.9	5.9	6.3	6.3
Alkalinity	7.0	5.4	10.3	7.7
Specific conductance (mmho)	19.2	16.2	27.0	19.5

the watersheds provide a mixture of trees, brush, and grassy openings that is nearly optimal for wildlife. Crab apples, berries, and treebrier are but a few of the abundant food-bearing species.

Evaluation of the water quality data shows that streams draining the Clover watersheds since 1957 almost always have met drinking water standards (U.S. Public Health Serv. 1962). The exception has been turbidity, but even on fully forested watersheds, channel scour during storms occasionally causes turbidity to exceed 5 JTU. It is inconceivable that water quality could be maintained at these levels unless erosion was prevented. Examination of the soils reinforced our opinion that revegetation had controlled erosion and stream sedimentation.

With little reason to dispute that erosion has halted, a more intriguing question remains: When was it controlled? The 1971 soil and vegetation surveys imply merely that erosion was unlikely under existing conditions. The history of land use suggests that farming ceased and that revegetation began about 1930. The extent of trees and brush on the 1945 aerial photograph and their growth in gullies by 1956 strongly suggest that serious erosion halted before 1945. Though the evidence over a 40-year period is not conclusive, decreases in streamflow—nonsignificant from the statistician's viewpoint—provide our best clue.

Significant decreases would indicate a more rapid reversion to forest than actually occurred during the period of measurement. So the nonsignificant decreases in annual streamflow from 1958 to 1971 are important; they indicate that the most rapid reversion to forest occurred in premeasurement years. Although Hibbert's (1967) review shows only that decreases in streamflow accompany reforestation, other evidence (Lull and Reinhart 1967) shows that most of the decrease occurs early in the reforestation process. Thus reforestation was well advanced before hydrologic observation began; water yields had peaked perhaps 20 years earlier, and most of the decreases in streamflow that had been sought occurred before 1958. On the basis of this indirect evidence, we conclude that erosion probably was inconsequential after 1935.

The Clover study has important implications today because concern for the quality of the environment has increased. During this brief history of land use, the environment underwent a nearly full circle of change. The primeval forest afforded maximum protection to soil and water; when the forest was gone and organic remains disappeared from the soil, erosion began. Reduced fertility and, more important, lowered infiltration, led to the deterioration of both soil and water. The food production demanded of the land overtaxed the soil's capacity to resist erosion.

The signs of dangerously depleted organic matter, erosion and sedimentation, must have been as obvious then as they are now, but they were not—indeed, they could not—be heeded. The economy of that time and place provided no means other than agriculture for human sustenance; and the farmers hung on until they were forced out by crop yields too meager even for marginal sustenance. When erosion decreased about 1935, the land was under grass and probably was near a peak of water productivity. Thirty years later, the land is near a peak of wildlife productivity. And in a few decades, the Clover watersheds will again be covered with useful hardwood forest.

As has proven true many times, when disturbing elements are removed, damaged watersheds in humid climates revegetate rapidly; soils are stabilized and stream sedimentation is prevented. For example, a badly eroded farm in North Carolina returned to its prefarming hydrologic condition within 2 years after farming ceased (Dils 1953). Erosion from logging roads was rapidly reduced in West Virginia merely by halting road use (Hornbeck 1967). Infiltration rates nearly doubled and soil erosion virtually halted after farmland purchased by the Tennessee Valley Authority was allowed to revegetate naturally (Rothacker 1953). But tillage, fertilization, and seeding were needed to revegetate more severely gullied soils in South Carolina (Metz 1958), and no amount of reclamation has halted soil loss on portions of the spectacularly eroded Copper Basin of Tennessee (Hursh 1948).

These examples indicate that rapid and complete hydrologic recovery of the farmed-out Clover watersheds was not unique to the Appalachian region. They also suggest that environmental quality has been adequately protected whenever erosion has not prevented natural revegetation on abandoned farmland.

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7 p. (U.S. Dep. Agric. For. Serv. Res. Pap. NE-392)

Thirteen years of hydrologic data from two contiguous small watersheds in West Virginia were analyzed to determine the effects on streamflow of natural reforestation on abandoned farmlands. From 1958 to 1970, streamflow on the watersheds was unchanged. The history of land use on the study area helps explain the apparent lack of hydrologic effects of reforestation. Long-term observation suggests that soil and water were protected adequately when the land became completely revegetated with any plant cover.

Keywords: Abandoned farmland, hardwood forests, soil erosion, small watersheds, water quality, water yield

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116.35

Black Walnut on Kansas Strip Mine Spoils: Some Observations 25 Years after Pruning

by Alex L. Shigo, Nelson F. Rogers,
E. Allen McGinnes Jr., and David T. Funk

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ABSTRACT

Dissections of 14 slow-growing black walnut trees on a strip-mine site revealed that bands of discolored heartwood were associated with pruned and nonpruned branch stubs. Ring shakes were associated with a few pruned and nonpruned stubs, especially with groups of stubs at the same position on the stem. The advantage of early pruning was that even the defects that developed were compartmentalized within the small nonmerchantable central core that was the diameter of the tree at the time of pruning.

THIS PAPER reports some observations on the internal condition of wood associated with pruned and nonpruned branch stubs on black walnut trees (*Juglans nigra* L.) 25 years after treatment. The trees were located on a partially graded coal-mine area in southeastern Kansas near Pittsburg. This study was initiated by F. Bryan Clark in 1950, and has been maintained since by Nelson F. Rogers.

Black walnut

Black walnut is one of our most valuable timber trees. Its value depends on many factors, but one of the most important is the amount of defect-free wood in the stem.

Dead branches, large, live, low branches, and poorly closed branch stubs are major causes of defect and the short lengths of clear wood that greatly reduce the quality and value of this tree. It seems that proper pruning early in the life of the tree might increase the quality of black walnut.

The original study in 1950

In January 1950, 720 black walnut trees grown from locally collected seed that had been planted by the Civilian Conservation Corps during the winter of 1935-1936 were pruned to 25, 50, or 75 percent of live crown, or were not pruned. The trees were part of a 2,000-acre planting of pure black walnut. At the time of pruning, the 14-year-old trees were 4 to 6 m in height, and 8 to 15 cm in diameter at breast height (dbh). The site is poor for the growth of black walnut (Geyer 1971). Additional details on the area (Rogers 1951; Geyer and Naughton 1971; Geyer and Rogers 1972; Geyer 1972) and on the study after 5 and 10 years (Clark 1955; Clark and Seidel 1961) have been published.

Dissection of trees in 1976

In April 1976, 14 trees considered representative of fast-growing and slow-growing specimens on the site were dissected with a chainsaw. We wanted to determine the internal condition of the wood associated with pruned and nonpruned branch stubs, basal seams, and mechanical wounds. The trees were located approximately 5 miles west of Pittsburg. Eight of these 14 trees (including 2 nonpruned trees) had been part of the initial study by Clark (Clark and Seidel 1961) (Table 1); the remaining 6 trees were not pruned and were cut as controls. On the study trees, the pruned stubs were dissected radially with a chainsaw or were split with an ax. The same procedure was followed for most of the stubs on the control trees.

Although only 14 trees were dissected, this sample was considered representative because more than 10,000 trees with similar defects have been dissected over a 17-year period (Shigo and Larson 1969; Shigo 1975, 1976; Solomon and Shigo 1976).

Table 1.—Increases in diameter and height growth from 1950 to 1976 for dissected black walnut trees near Pittsburg, Kansas

Tree number	Percentage of live crown removed	Dbh		Height	
		January 1950	April 1976	January 1950	April 1976
		cm		m	
359	75	14	29	7	14
358	75	10	22	6	12
352	0	13	24	8	14
346	0	8	17	7	13
338	50	13	20	7	12
314	75	14	22	9	13
82	75	12	20	7	12
340	75	14	17	8	11

Observations after 25 years

A few trees were more than 40 cm in dbh; this indicates that some trees were able to grow rapidly on the better areas of this poor site. Most of the trees were much smaller. Heavy, low, dead branches, and large, low, living branches were common on most nonpruned trees (Fig. 1), but there were several nonpruned trees that had large sections of clear stem with well-closed branch stubs (Fig. 2). This indicates that a few trees will produce fair-quality wood without treatment on a poor site.

Large bumps or callus mounds were common around nonpruned stubs (Fig. 3). Dissections showed that discolored heartwood was associated with these stubs (Fig. 4). A dark fluid oozed from a few stubs (Fig. 5); this was a sign of wetwood and discolored heartwood.

Cavities behind many partially closed stubs were inhabited by ants (Fig. 6); ants also were active on stubs during the dissections.

Tree 340 grew slowly after pruning (Figs. 7 and 8), while Tree 359 continued to grow fairly rapidly (Fig. 9) (Table 1). The trees were approximately the same diameter at the time of pruning, and they were both pruned to 75% of live crown (Table 1). The pruning wounds were still open on Tree 340 (Fig. 8), but all of the pruning wounds on the faster growing tree had closed (Fig. 10).

Dissections showed that the stubs were sound and were covered by sound wood in the faster growing trees (Fig. 11). But dark bands of wood were associated with wounds even in the fastest growing trees whose stubs had closed rapidly (Fig. 12). These bands were in the sapwood rings that had been formed just before pruning (Figs. 12 and 13). The darkest band was in the youngest growth ring that was present at the time of wounding. The ring that formed after pruning (the 1950 growth ring) was a different color.

After some branch samples were dried in the laboratory, a separation began to develop between the 1949 and the 1950 growth rings (Fig. 14). This separation was the most pronounced in samples that had several pruned stubs at approximately the same positions (Fig. 15). In the field we were able to pull apart these samples because areas of ring shake had already formed in the living tree—this was the case with pruned and nonpruned stubs.

The dark band associated with the 1949 growth ring was obvious several meters above and below the pruned stubs (Fig. 16).

Bands of dark wood were also associated with mechanical wounds. Some trees were wounded when they were very young. It appeared that some of the wounds were caused by fire, because charcoal was present within the wound. It is also possible that some of the wounds were caused by the sunscald that occurred after the 1954 growing season and before the 1955 season (Clark 1961). Regardless, many trees had basal seams associated with wounds (Fig. 17).

A dark fluid flowed from some of the seams. Dissections showed that the primary seam was associated with the inrolled callus around the original wound, but that other seams were associated with cracks that formed from the inside and developed outward (Figs. 18 and 19). When decay was associated with these wounds, it was confined to the tissues present at the time of wounding. Decay associated with stubs was also confined to the tissues present at the time the branch died (Fig. 20).

Discussions

The benefits of pruning were obvious in most trees. Pruning increased the lengths of clear wood, and sound clear wood covered the stubs on the fast growing trees. Observations by Clark (1961) 10 years after pruning indicated that most pruning wounds had closed. A few were still open on the slow-growing trees. Some of the pruning wounds on Tree 340, a slow-growing tree, were still open 25 years after pruning. Wound closure is associated with growth rate (Neely 1970), and wounds on slow-growing trees do not close rapidly. But wound closure is a minor part of the wound response. Wounds close on the outside and compartmentalize on the inside. It is the inside compartmentalization, rather than the external closure, that is most important (Shigo et al. 1977a, 1977b).

The internal condition of the wood associated with the stubs and wounds on the 14 dissected trees did not differ from that of thousands of others dissected over a 17-year period. The results of these studies have helped in developing a concept of compartmentalization of decay in trees (Shigo 1975, 1976); that is, a tree is a compartmented plant, and that after wounding, its defense system is geared to minimizing the number of compartments that are infected. After wounding, the injured cambium begins to form new tissue—the barrier zone (Sharon 1973). McGinnes (1975) has described this zone in black walnut. The barrier zone confines the infection to the tissues present at the time of wounding, and new tissues that form are not infected. The barrier zone was obvious in the pruned and nonpruned dissected samples. The dark band of wood was on the pith side of the barrier zone, and it extended for great distances above and below the wounds.

The barrier zone was also the site of ring shakes; this was shown by McGinnes (1975) for black walnut. Ring shakes are associated with wounds (McGinnes et al. 1971, 1974a, 1974b; Shigo 1972), but not all wounds form ring shakes. Ring shakes are important defects in black walnut (McGinnes 1968, 1975; McGinnes and Shigo 1975).

The results of the dissections of the stubs suggest that care should be taken not to remove too many branches from one location on the stem during one pruning period. This agrees with the recommendation by Clark (1955, 1961).

In addition to the possibility of ring shakes forming after the pruning of branch clusters, the bands of dark wood could also be defects (McGinnes 1975). Color and patterns of color are important factors in determining the quality and value of black walnut (Moslemi 1967; Nelson et al. 1969; Maeglin and Nelson 1970).

It may be that the most recently formed rings of sapwood are altered in some way at the time of pruning; this altered wood may later develop darker pigments as it is transformed into heartwood. Or the formation of heartwood may be stalled by the wounds, as it is in white oak (McGinnes and Shigo 1975). Infection of the sapwood exposed by the pruning wound may also affect subsequent pigmentation. Regardless of the exact cause, the black bands were associated with the stubs even at some distance above and below the wounds. This helps explain the bands of differently colored heartwood that are common characteristics of black walnut, especially in slow-growing trees on poor sites. The intensity of the bands could reflect a tree's history of branch stubs, and an individual tree's response to branch stub wounds or to other injuries to the wood (McGinnes 1975).

The basal seams were caused by wounds; these seams are often called "frost cracks". The anatomy of these defects was clarified by McGinnes et al. (1976); the seams start from the inside and develop outward.

Great caution must be taken in interpreting these results because the trees are growing on a very poor site. Results of these dissections and the dissections of thousands of other trees indicate that all trees respond to wounds in a similar way—a barrier zone is formed and the tissues along the zone are discolored. But the intensity of the response and the extent of defects associated with it depend on many factors.

The adverse conditions under which the black walnut trees in this study were growing could have had a strong effect on the intensity and the extent of defects associated with the branch stubs.

In conclusion, pruning is not a "cure all" for black walnut. It may be highly beneficial for some trees, but pruning may cause only more problems for others.

Proper pruning at an early age still offers the potential advantage of producing longer lengths of clear wood. Pruning also may result in ring shakes, and in bands of dark heartwood in the small nonmerchantable central core.

A possible solution may be selecting for growth those trees that respond effectively to pruning wounds. Results of recent research suggest that the wound response is under genetic control (Shigo et al. 1977a, 1977b). Some trees of the same species respond to wounds more effectively than others; this was obvious with the trees dissected on the mine spoils. If trees that have a strong response to wounds are pruned, the internal defects will be slight. And even the defects that do develop will be compartmentalized in the small central core that was the diameter of the tree at the time of pruning.

Research indicates that the potential is great for growing high-quality black walnut trees on poor sites such as strip-mine spoils. This can be done through studies on genetics and compartmentalization.

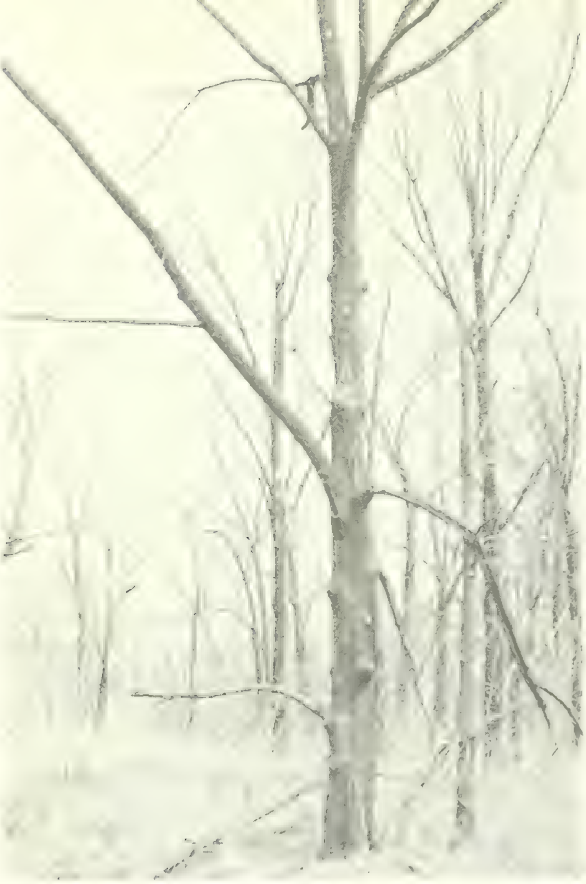


Figure 1.—Fast-growing nonpruned black walnut with many dead branches, poorly closed branch stubs, and large, low living branches.

Figure 2.—Medium growing nonpruned black walnut with well-closed branch stubs, and a long section of clear stem.

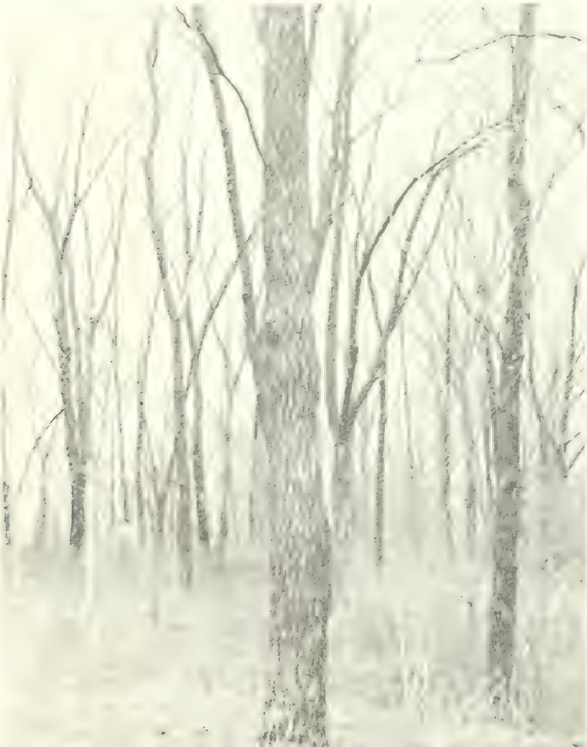
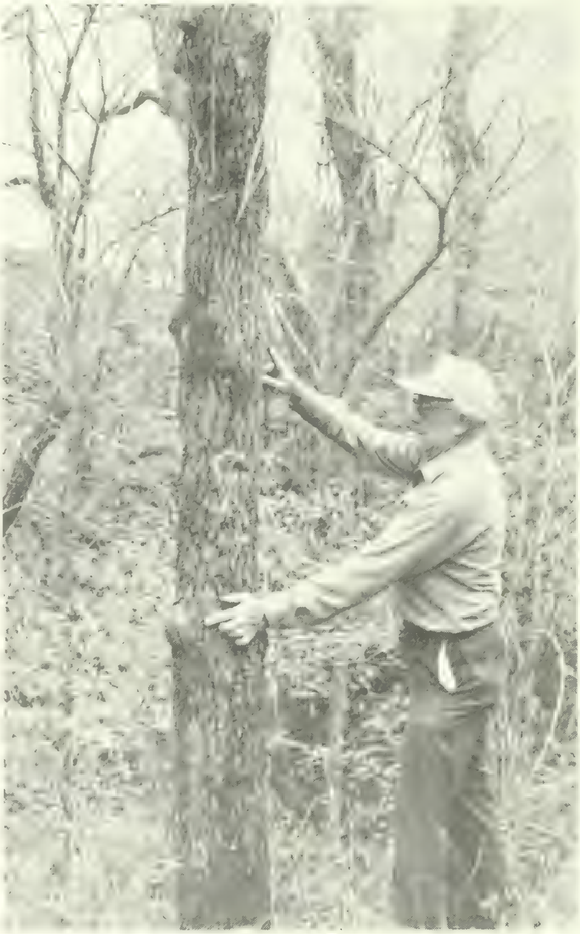


Figure 3.—Large bumps or callus mounds around poorly closed nonpruned branch stubs.



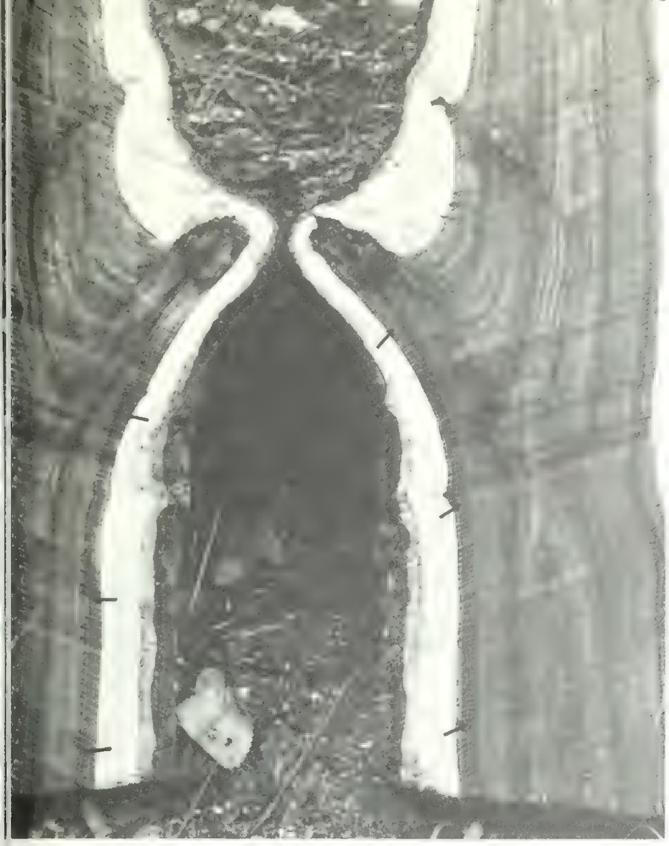


Figure 4.—Dissection of stub shown in Figure 3 (left hand of person). Note dark band of discolored heartwood associated with stub (arrows).

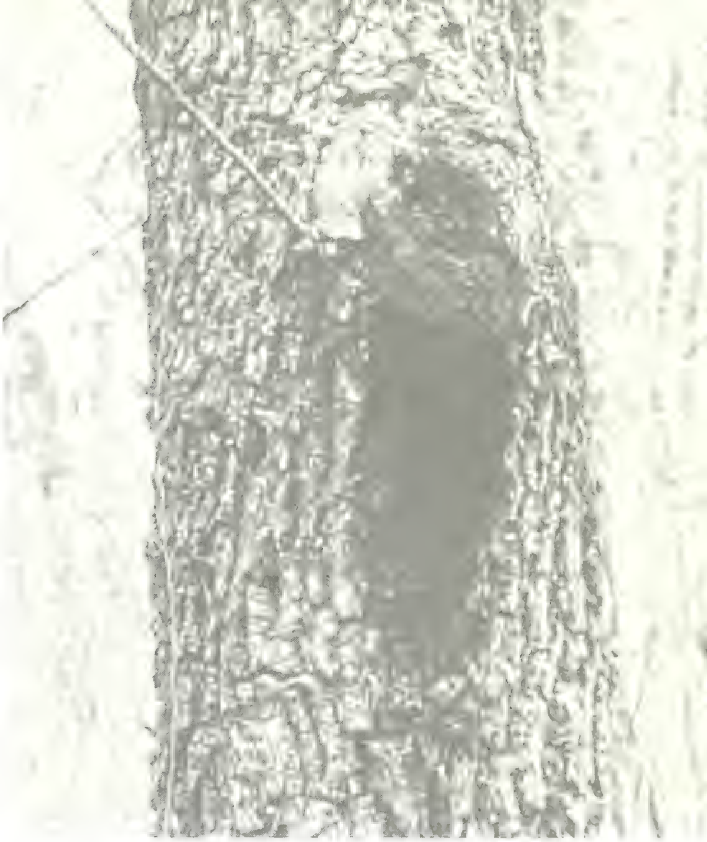


Figure 5.—Dark fluid flowing from an open stub indicates internal wetwood and darkly discolored heartwood.

Figure 6.—Cavities behind swollen stubs inhabited by ants; this was common in many nonpruned trees.

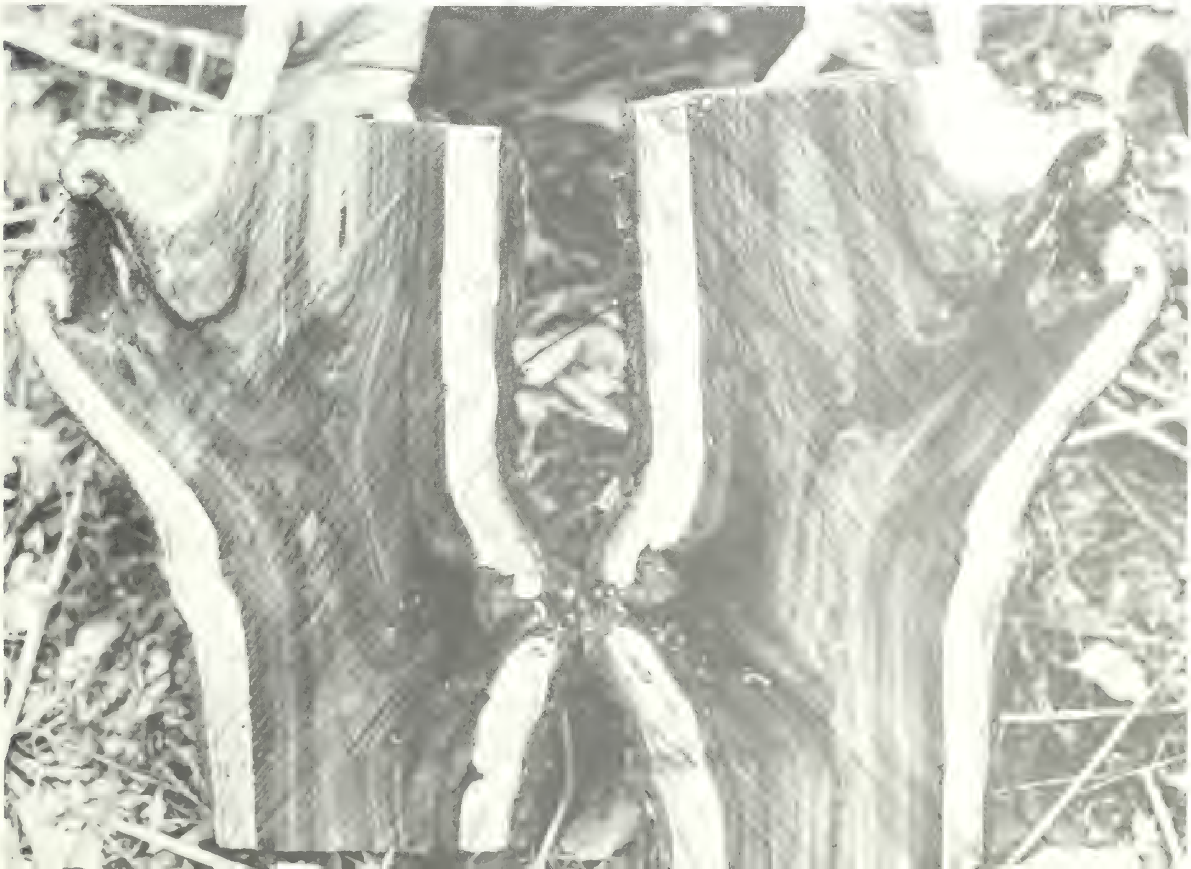


Figure 7.—These trees (large tree: 359; small tree: 340) were approximately the same diameter when both were pruned to 75% of live crown.

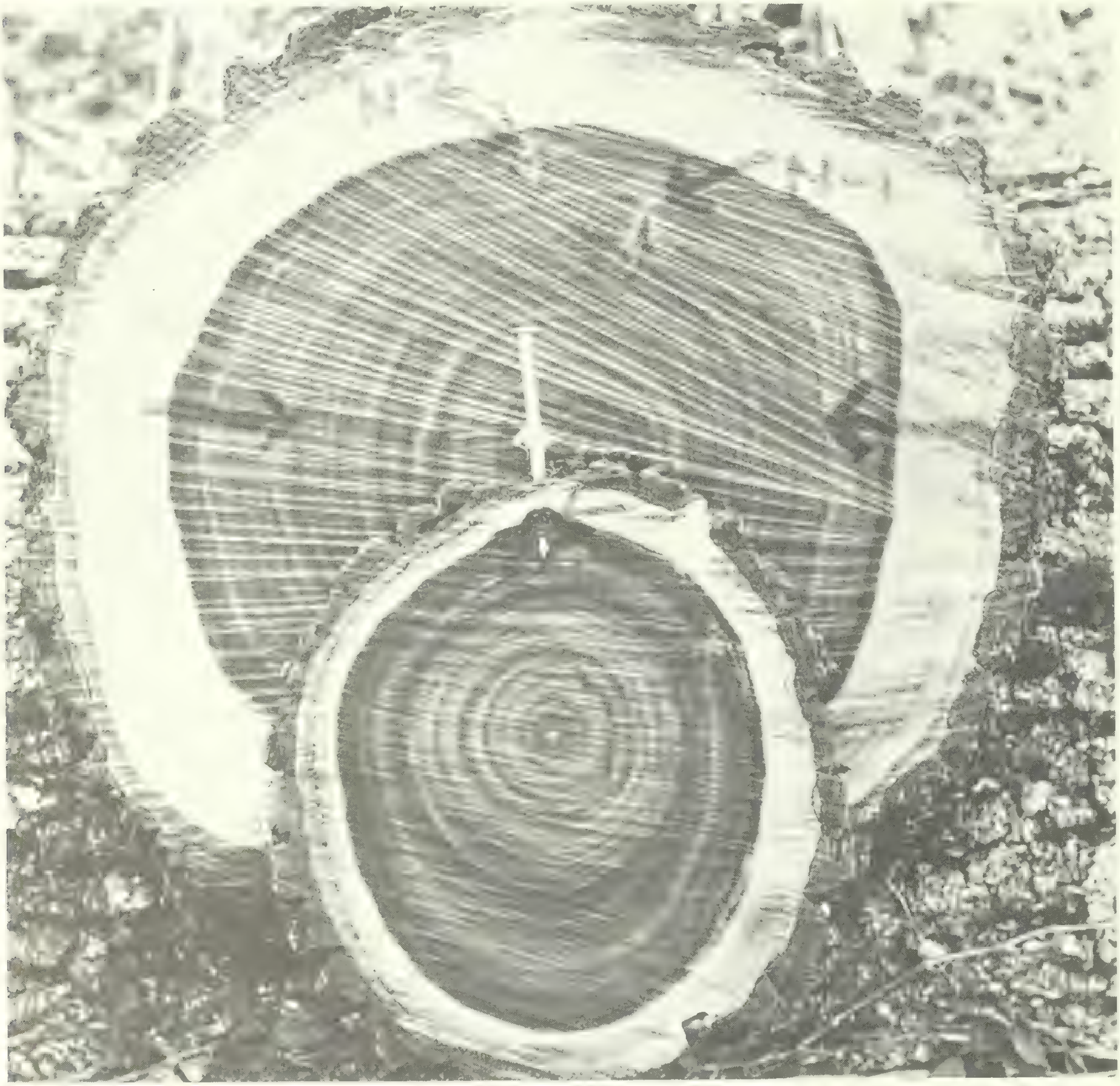


Figure 8.—Tree 340 grew slowly after pruning. It still had some open stubs after 25 years (arrows).

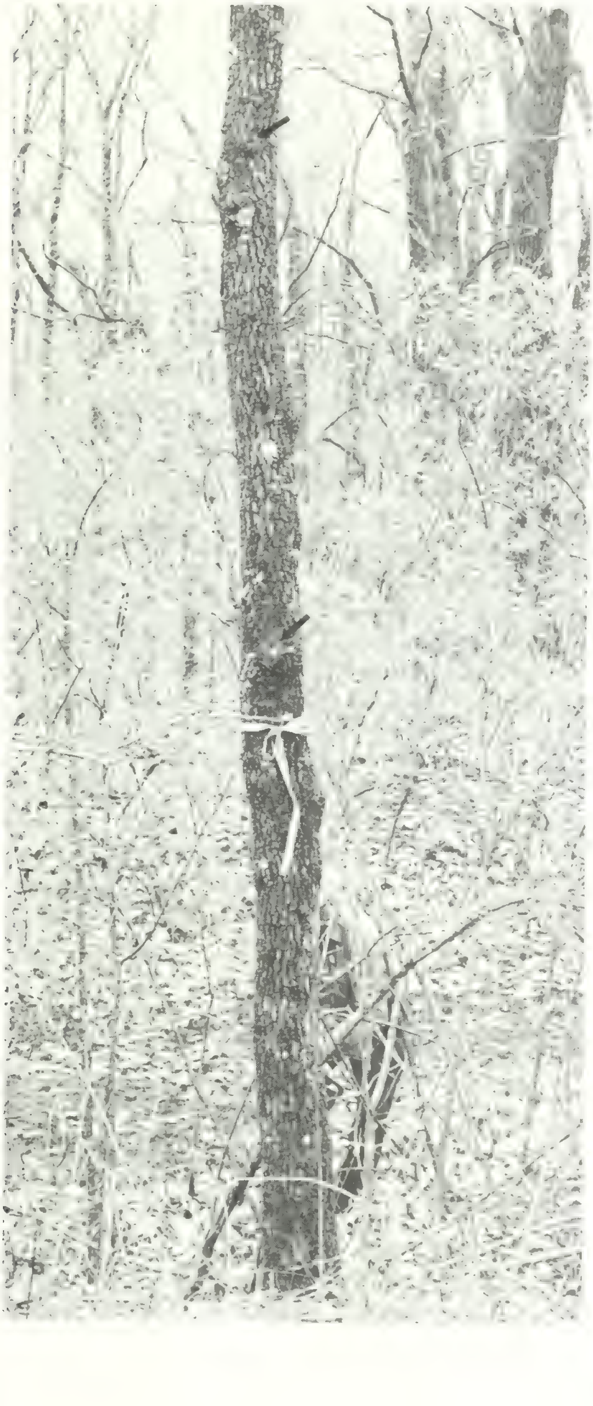
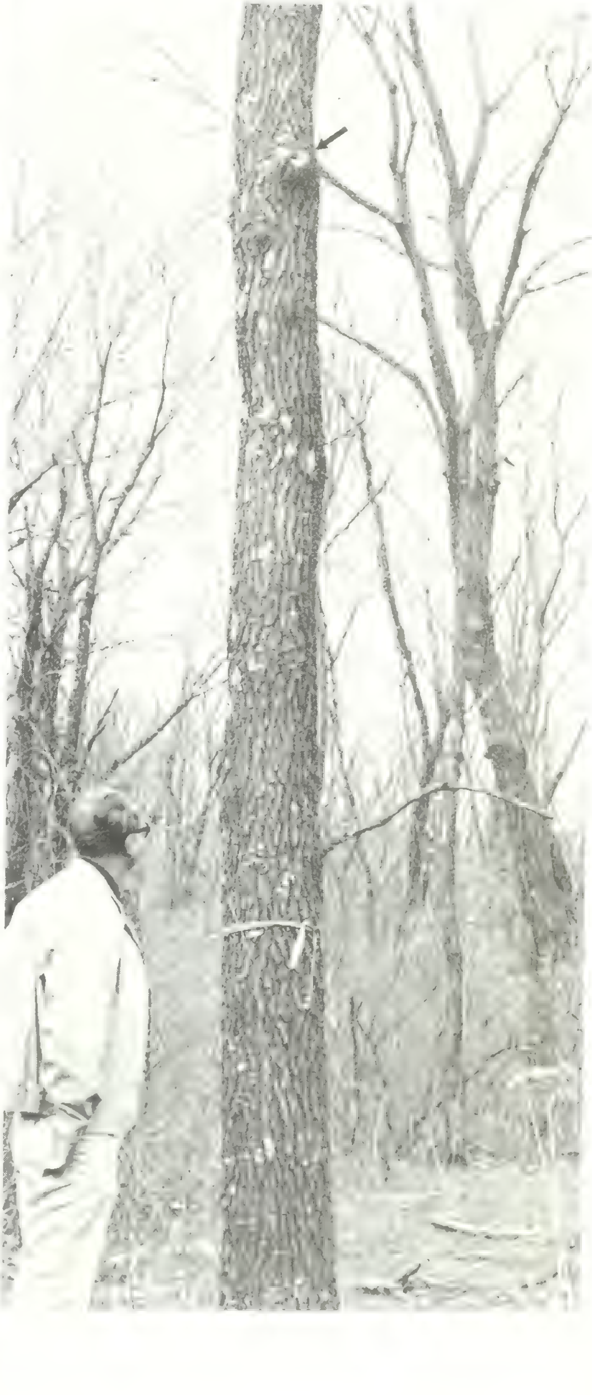


Figure 9.—Tree 359 was a fast-growing tree that had well-closed pruned stubs. The arrow shows the lowest live branch that was present after pruning (see Figure 15 for dissection of this branch).



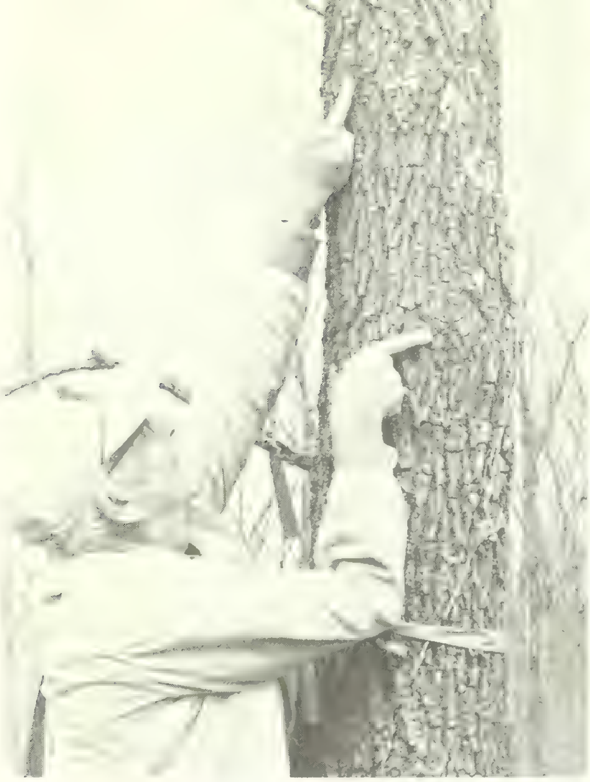


Figure 10.—Well-closed pruning wounds on Tree 359.

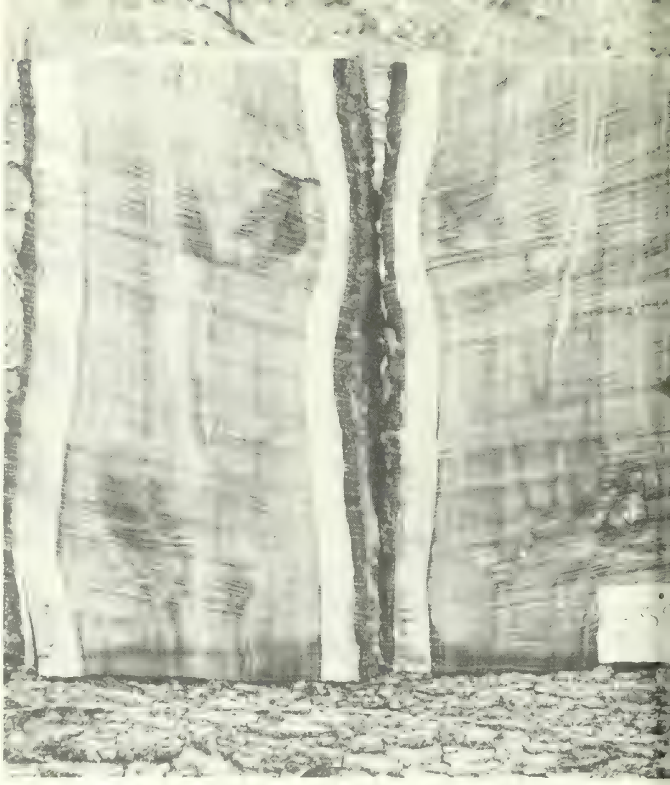


Figure 11.—Dissection of stubs shown in Figure 10; clear wood covered the stubs.

Figure 12.—Arrows point to the diameter of Tree 359 at the time of pruning. Note the dark band of heartwood that formed in the tissues present at the time of pruning.

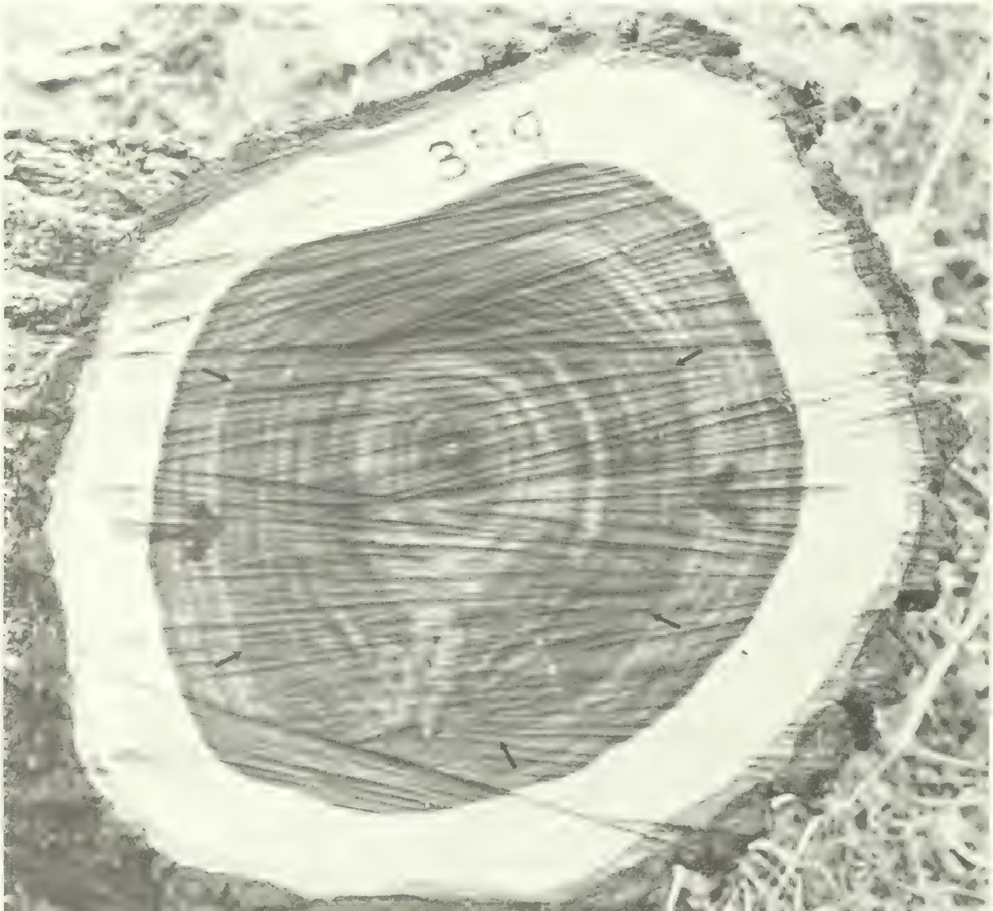


Figure 13.—Dark bands of heartwood were associated with the closed stubs (arrows 1). The central dark core indicates the diameter of the tree when it was wounded at the base early in its life (arrows 2).

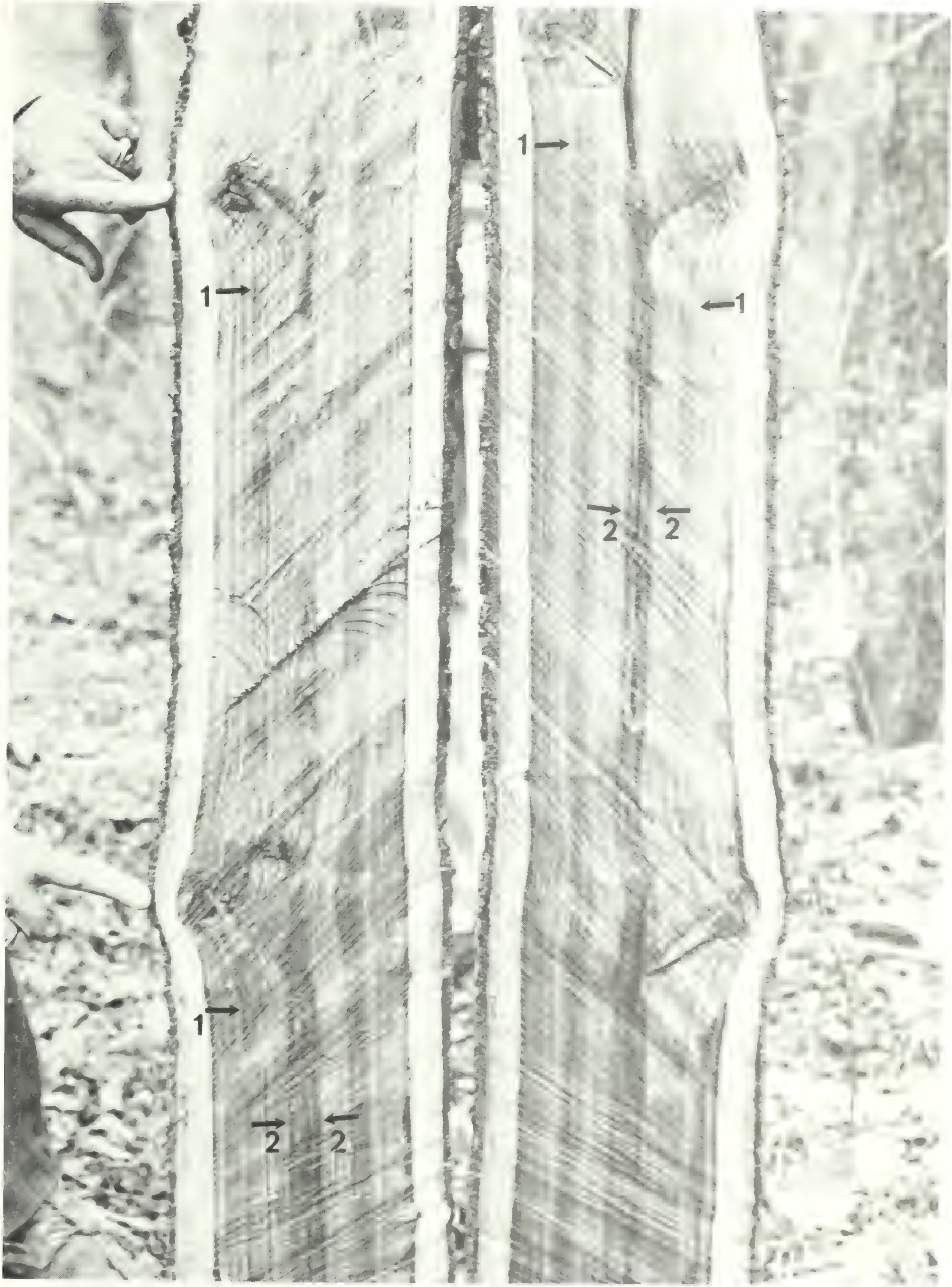


Figure 14.—Closeup of well-closed pruned stub in Tree 359. Note ring shake line at the barrier zone, and band of dark heartwood (arrows).

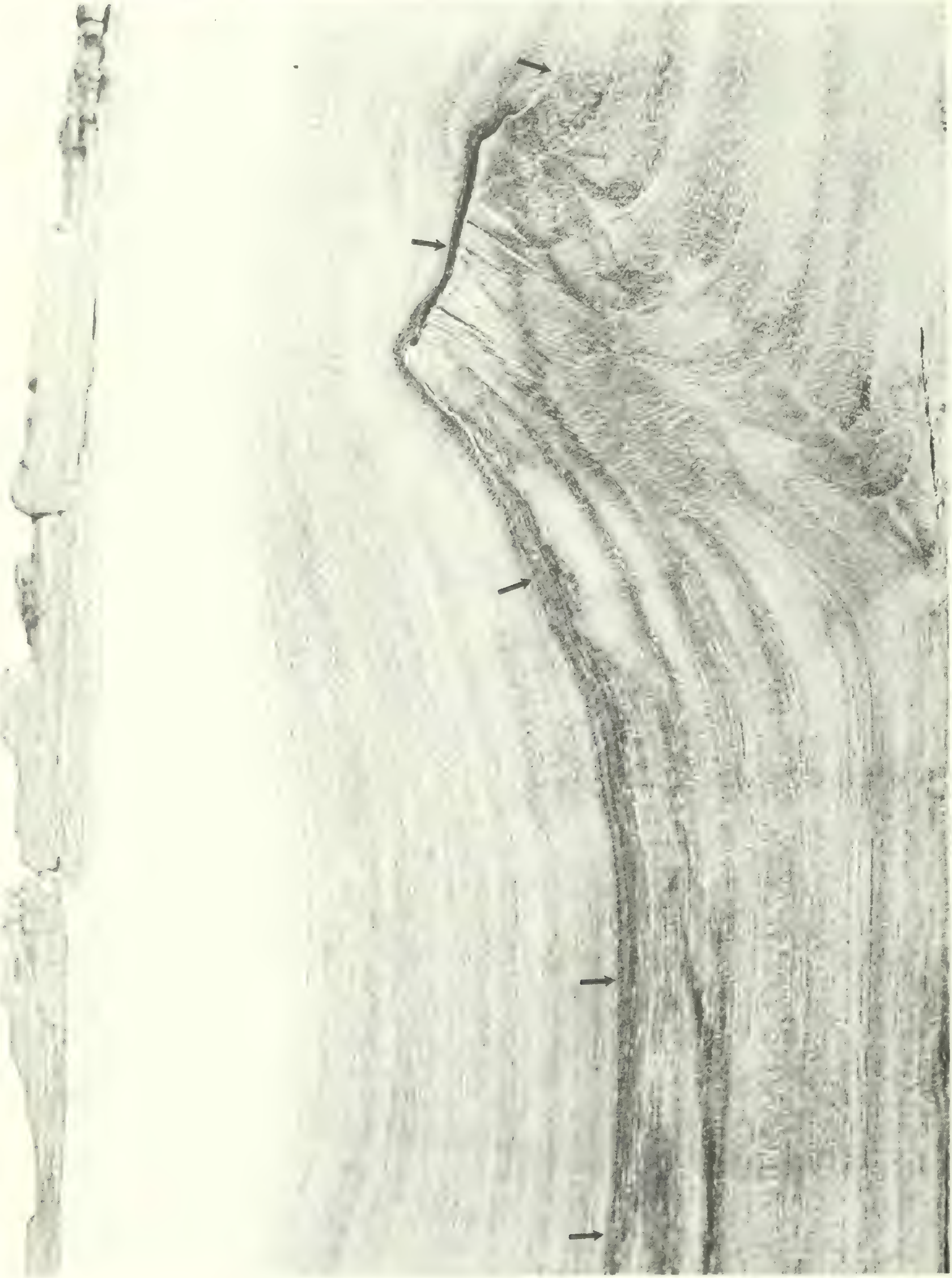
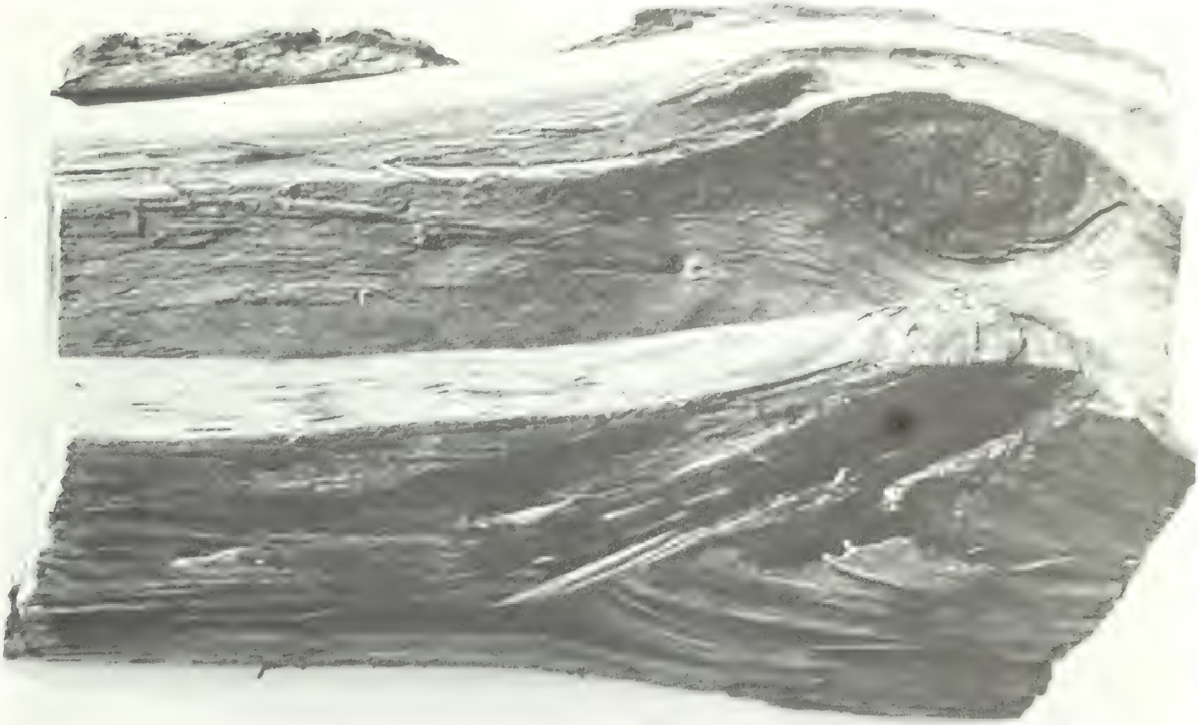


Figure 15.—Ring shake associated with pruned stub.



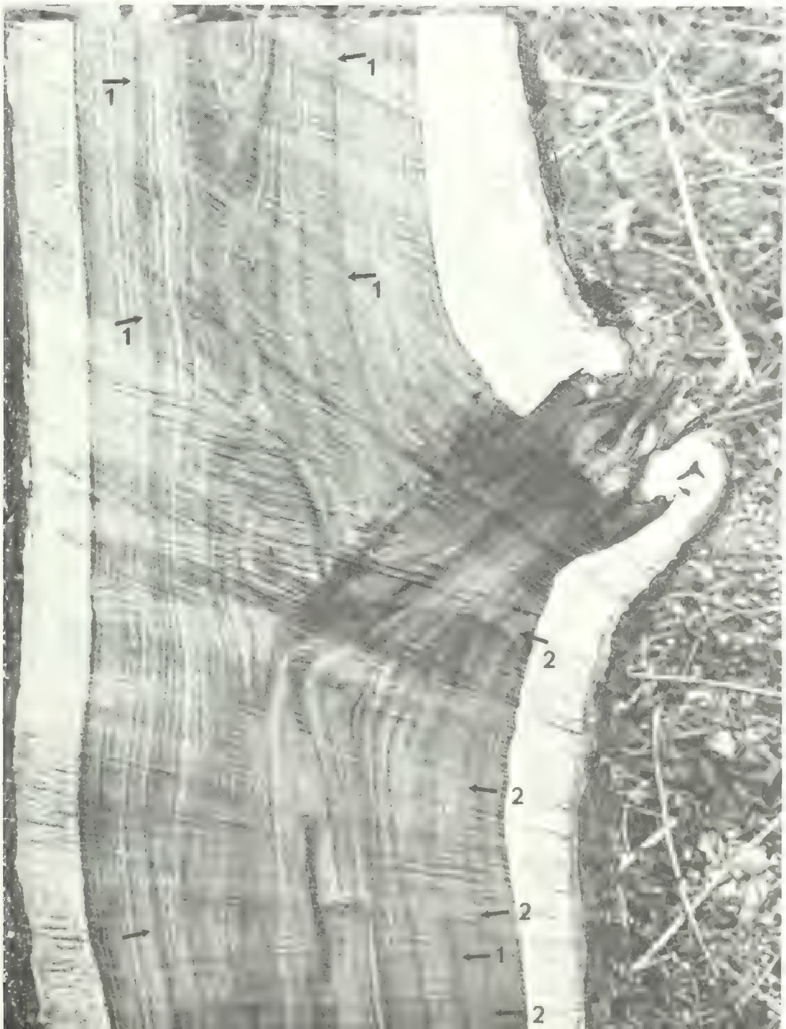


Figure 16.—Dissection of nonpruned stub on pruned Tree 359. Note dark lines that indicate diameter of tree when pruned below (arrows 1), and line associated with the nonpruned stub shown here (arrows 2). Note small ant galleries and light-colored decay in stub.

Figure 17.—Basal seams with dark exudate; often incorrectly called "frost cracks", basal seams actually are wound cracks.

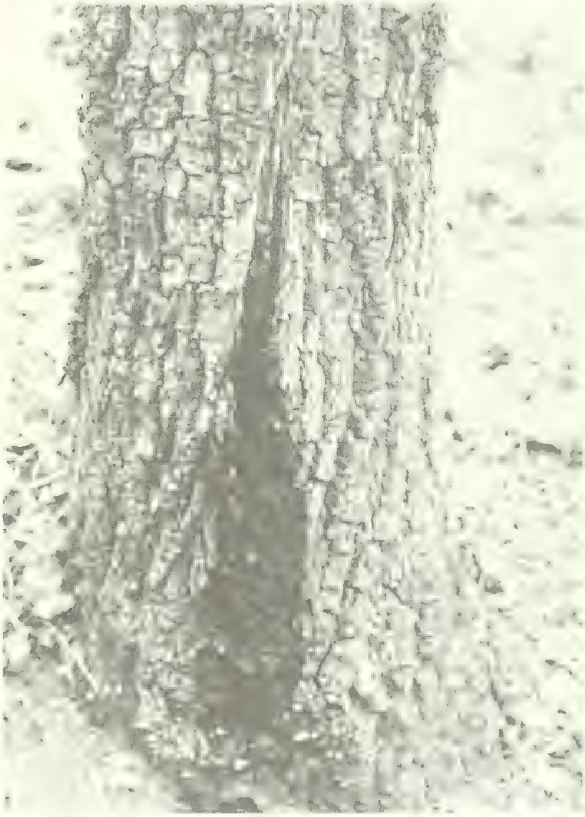
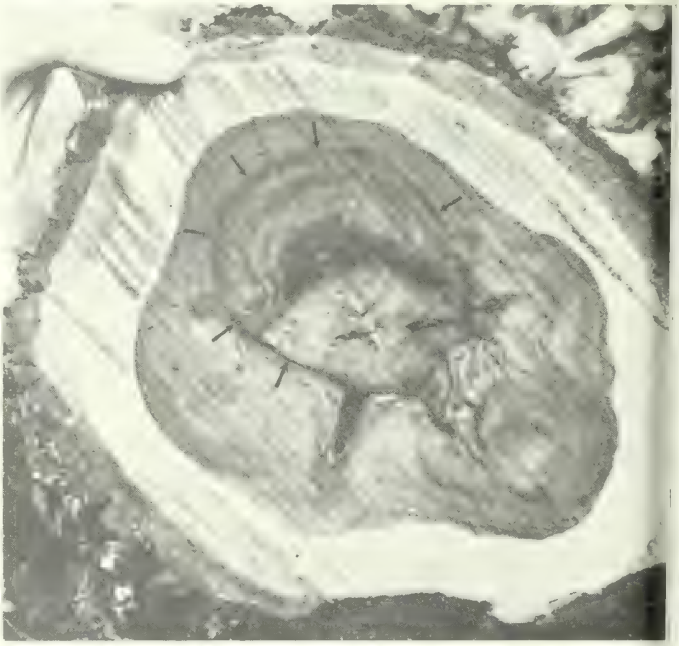


Figure 18.—Dissection of tree shown in Figure 17. Note the dark line formed at the time of wounding (arrow). The cracks start from the inside and develop outward as the temperature decreases and shrinks the diameter of the tree.



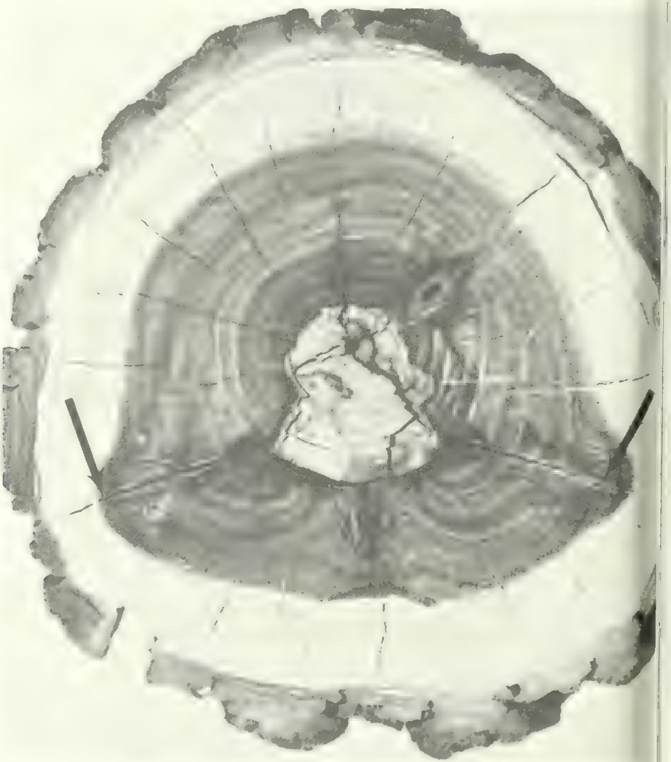
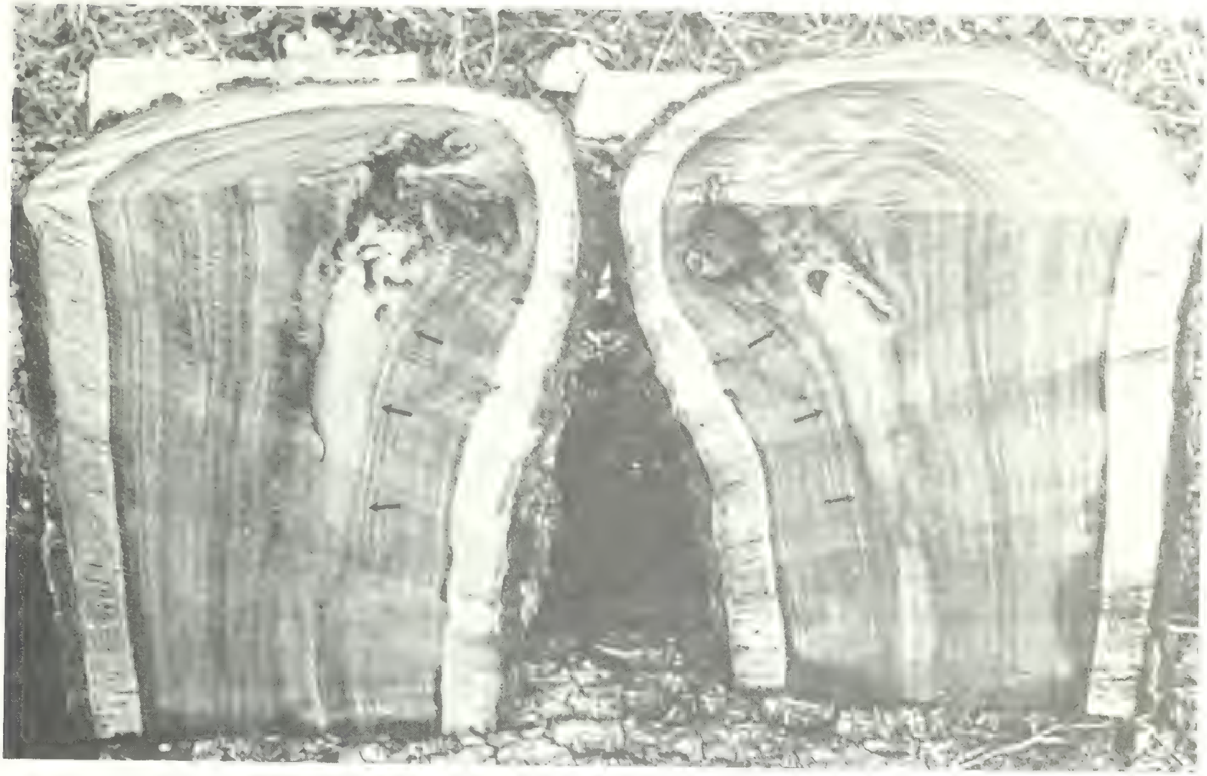


Figure 19.—Internal cracks (arrows) associated with the edges of the wound often move outward, especially during cold weather. Wounds cause the cracks to form, and the cold causes them to move outward.

Figure 20.—Although decay was associated with this stub, and the stub was inhabited by ants, the tissues that formed after the stub died were not infected (arrows). Defects associated with stubs are compartmentalized.



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Dissections of 14 slow-growing black walnut trees on a strip-mine site revealed that bands of discolored heartwood were associated with pruned and nonpruned branch stubs. Ring shakes were associated with a few pruned and nonpruned stubs, especially with groups of stubs at the same position on the stem. The advantage of early pruning was that even the defects that developed were compartmentalized within the small nonmerchantable central core that was the diameter of the tree at the time of pruning.

Keywords: Compartmentalization, discolored wood, pruning

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Response to Crop-Tree Release: Sugar Maple, Red Oak, Black Cherry, and Yellow-Poplar Saplings in a 9-Year-Old Stand

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MANUSCRIPT RECEIVED FOR PUBLICATION 24 APRIL 1977

ABSTRACT

Crop trees were released in an Appalachian hardwood stand (site index 70 for northern red oak) that had been clearcut 9 years earlier. We released 134 yellow-poplar, red oak, black cherry, and sugar maple stems of seedling origin to a 5-foot radius around the bole of each study tree; 140 comparable stems were not released. These trees were dominant, codominant, or intermediate, and all treated trees were released to a dominant crown position.

On the basis of results 5 years after treatment, we do not recommend releasing crop trees of seedling origin for the species, site, and methods used in this study. Also, grapevines seriously damaged about one out of four trees that were living 5 years after treatment.

Response to Crop-Tree Release: Sugar Maple, Red Oak, Black Cherry, and Yellow-Poplar Saplings in a 9-Year-Old Stand

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INTRODUCTION

THE RESPONSE of 7-year-old crop trees to release on excellent sites (site index 80 for northern red oak) and on fair sites (site index 60) was discussed by Trimble (1973, 1974a), In this paper we discuss the response to the release of young hardwood crop trees of seedling origin in a 9-year-old clearcut stand on a good site (site index 70) in the central Appalachians.

We used a 9-year-old clearcut area because, for this particular stand, 9 years was the earliest age at which the stand canopy closed and crown classes could be distinguished. By selecting and releasing crop trees at an early age, it may be possible to control species composition and increase the growth of the most merchantable trees.

DESCRIPTION OF THE AREA

The study was made on the Fernow Experimental Forest near Parsons, West Virginia. The soil is a well-drained Calvin channery silt loam derived from sandstone and shale. The elevation of the study area is about 2,000 feet, and the slope is about 40 percent. Annual precipitation averages 58 inches; the annual frost-free period is about 135 days.

The 9-year-old stand developed after a 55-year-old, well-stocked, unmanaged 12-acre stand was clearcut. An average of 10,600 board feet (International 1/4-inch rule) of sawtimber per acre had been removed; all stems 2.0 inches in diameter at breast height (dbh) and larger had been cut.

METHODS

Four species were studied: yellow-poplar (*Liriodendron tulipifera* L.); northern red oak (*Quercus rubra* L.); black cherry (*Prunus serotina* Ehrh.); and sugar maple (*Acer saccharum* Marsh.). For each species we selected 11 to 40 well-formed, vigorous trees of seedling origin in each of 3 crown classes. Approximately half of the crop trees in each crown class (134) were selected for release; 140 others were not released.

Release consisted of cutting all woody stems that were at least half as tall as the crop trees within a 5-foot radius around each study tree (Figs. 1,2). Grapevines in the crowns of crop trees were cut near groundline.

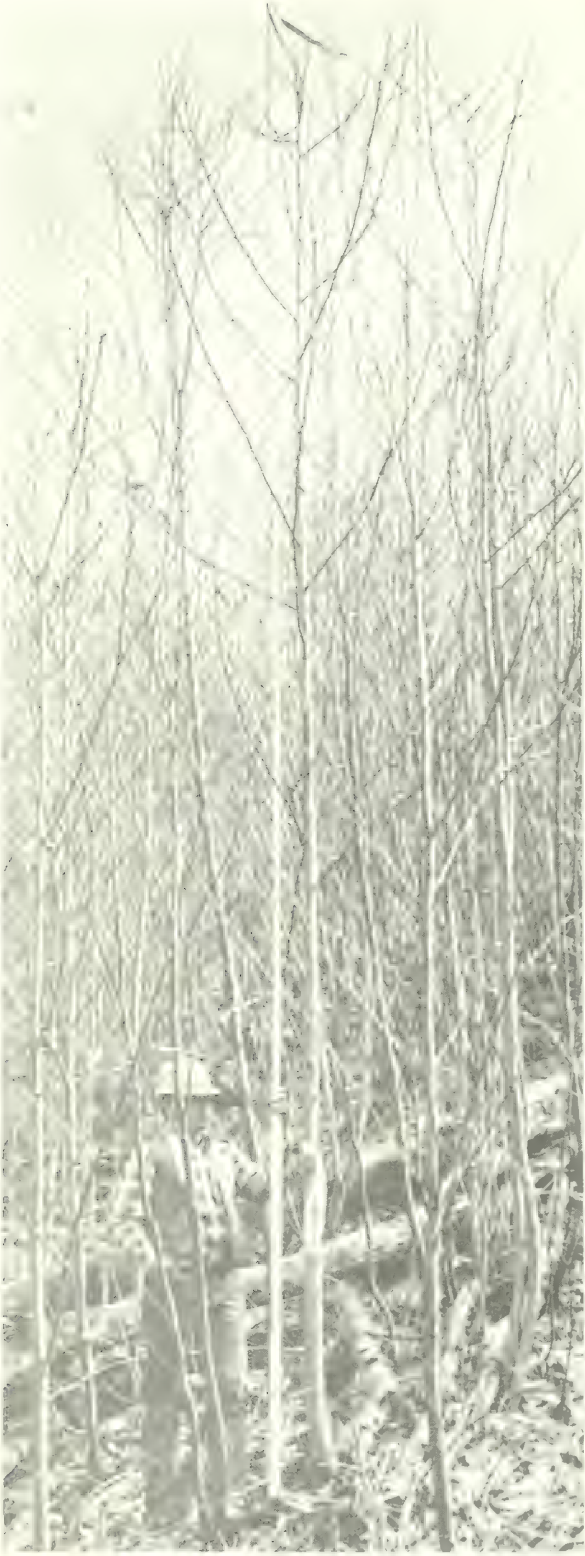

Figure 1.—A yellow-poplar crop tree of seedling origin before release. The tree is 22 feet tall and is 3 inches in diameter at breast height.

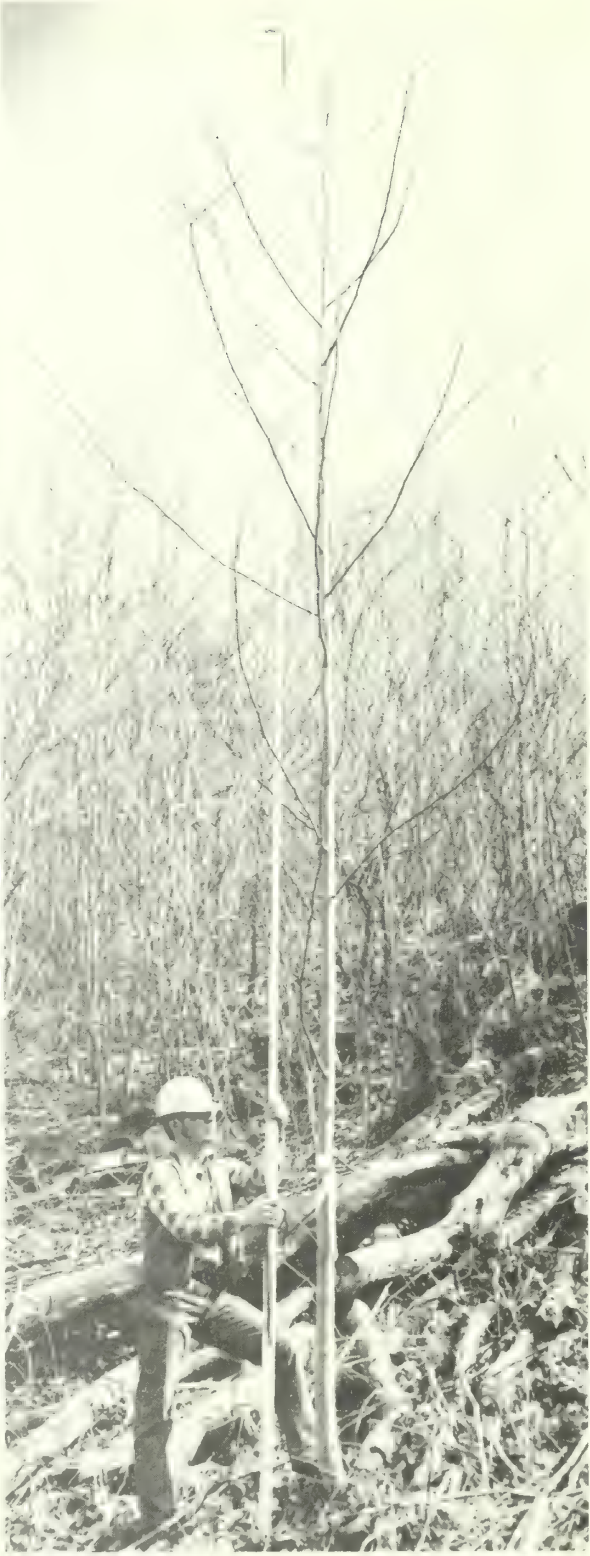

Figure 2.—The same yellow-poplar after release.

Total height, clear bole length, and dbh were measured for each sample tree before treatment, and 5 growing seasons after treatment when the clearcut stand was 14 years old. Five years after treatment, the crown position was reclassified and the study trees were reevaluated as potential crop trees. We used a t-test to determine which differences between treated and control trees were significant at the 5 percent level.

RESULTS

Twenty-one of the 274 crop trees (8 percent) were dead 5 years after treatment; and grapevines severely damaged 64 of the 274 trees (23 percent). This damage included top and limb breakage in addition to the bending of crop trees, resulting in poor stem form and sometimes in death. To distinguish between effects of release and those of grapevine damage, we will first discuss all of the study trees, then the 189 undamaged crop trees that were alive 5 years after treatment, and finally the 64 damaged crop trees.

All trees in the study

Effect on potential crop-tree classification. At age 14, only 64 of the 274 study trees (23 percent) were still considered potential crop trees. This judgement was based on crown class, tree vigor, and stem form. We found that release had not been beneficial—33 of these 64 potential crop trees had not been released (Table 1).

Crop trees not damaged by grapevines

Effect on crown class. Only seven crop trees improved in crown class during the 5-year treatment period; about 80 percent regressed. This was true for both released and nonreleased trees, though all of the treated trees had been released to a dominant crown position (Table 2). Of the 54 originally dominant released and nonreleased trees, 40 (74 percent) were dominant or codominant 5 years after release. However only 21 of the original 81 (26 percent) codominant nonreleased and released study trees were still codominant.

The remaining dominant and codominant trees became intermediate or overtopped, or died. Nearly all of the originally intermediate trees were intermediate, overtopped, or dead 5 years after treatment. Of the 156 originally codominant and intermediate trees, 128 were intermediate, overtopped, or dead.

Effect on height growth. Only the released intermediate red oak and codominant black cherry crop trees had significantly greater height growth than the nonreleased comparison trees (Table 3). But the released dominant yellow-poplar trees grew significantly less than the control trees.

Table 1.—Number of potential crop trees before and 5 years after treatment

Species	Treatment	Dominant		Codominant		Intermediate	
		Before treatment	After treatment	Before treatment	After treatment	Before treatment	After treatment
Sugar maple	Release	19	8	17	1	15	0
	Nonrelease	11	6	9	1	10	1
Red oak	Release	5	1	20	6	20	2
	Nonrelease	14	8	20	3	13	0
Black cherry	Release	10	5	9	2	3	1
	Nonrelease	12	7	16	3	7	0
Yellow-poplar	Release	5	2	5	3	6	0
	Nonrelease	6	2	10	1	12	1
All species	Release	39	16	51	12	44	3
	Nonrelease	43	23	55	8	42	2

Table 2.—Change in crown class of study trees 5 years after treatment

Crown class before treatment	Treatment	Crop trees at beginning of study	Crown class (5 years after treatment)				Dead
			Dominant	Codominant	Intermediate	Overtopped	
		Number					
			SUGAR MAPLE				
Dominant	Release	9	0	6	0	1	2
	Nonrelease	10	0	7	1	0	2
Codominant	Release	12	0	3	6	2	1
	Nonrelease	5	0	0	1	4	0
Intermediate	Release	13	0	0	3	10	0
	Nonrelease	7	0	1	1	4	1
			RED OAK				
Dominant	Release	2	0	1	1	0	0
	Nonrelease	11	0	8	2	0	1
Codominant	Release	17	0	6	6	4	1
	Nonrelease	16	0	4	9	3	0
Intermediate	Release	18	0	2	5	7	4
	Nonrelease	11	0	0	1	9	1
			YELLOW-POPLAR				
Dominant	Release	5	0	5	0	0	0
	Nonrelease	4	2	1	1	0	0
Codominant	Release	5	2	2	1	0	0
	Nonrelease	9	0	2	3	2	2
Intermediate	Release	6	0	0	1	4	1
	Nonrelease	12	0	1	2	8	1
			BLACK CHERRY				
Dominant	Release	6	1	3	0	0	2
	Nonrelease	7	1	5	0	1	0
Codominant	Release	6	0	2	2	0	2
	Nonrelease	11	0	2	5	4	0
Intermediate	Release	3	0	1	1	1	0
	Nonrelease	5	0	0	0	5	0

Comparisons of height growth for released and control sugar maple and red oak were inconclusive. However in five of six cases the released black cherry and yellow-poplar crop trees grew faster than the control trees. Some of these differences in growth may have been due in part to initial differences in height. Fourteen years after clearcutting, the average height of the tallest sugar maples was about 28 feet; the average height was 26 feet for the tallest red oaks, 32 feet for yellow-poplars, and 34 feet for black cherries.

Effect on diameter growth. The released codominant and intermediate yellow-poplar crop trees had significantly greater diameter growth than the nonreleased trees (Table 4). However, among codominant red oaks, the control trees had significantly less growth than the released trees. The released trees had larger diameter growth than the control trees in 10 of 12 categories for species and crown class.

For red oak and sugar maple, the crop trees that had been in the dominant crown class at 9 years averaged about 2.5 inches in dbh at 14

Table 3.—Average height of study trees before and 5 years after treatment

Crown class before treatment	Treatment	Crop trees living at 14 years	Total height At 9 years	Total height At 14 years
		Number	*Feet*	
		SUGAR MAPLE		
Dominant	Release	7	18.3	28.2
	Nonrelease	8	18.1	28.2
Codominant	Release	11	15.5	24.8
	Nonrelease	5	15.1	21.6
Intermediate	Release	13	13.9	19.1
	Nonrelease	6	13.7	19.8
		RED OAK		
Dominant	Release	2	17.5	27.9
	Nonrelease	10	14.7	25.4
Codominant	Release	16	14.2	23.0
	Nonrelease	16	12.9	22.9
Intermediate	Release	14	12.3	18.3*
	Nonrelease	10	11.5	15.1
		YELLOW-POPLAR		
Dominant	Release	5	13.3	30.1*
	Nonrelease	4	14.1	34.2
Codominant	Release	5	13.8	32.2
	Nonrelease	7	10.9	26.3
Intermediate	Release	5	13.2	23.6
	Nonrelease	11	10.8	18.4
		BLACK CHERRY		
Dominant	Release	4	24.2	39.7
	Nonrelease	7	16.8	30.1
Codominant	Release	4	16.3	32.3*
	Nonrelease	11	15.7	25.9
Intermediate	Release	3	13.6	21.8
	Nonrelease	5	13.2	18.7

* $P<0.05$

years. Similarly, the dominant yellow-poplar and black cherry crop trees averaged about 3.5 inches in dbh.

Effect on length of clear bole. Most of the released trees had shorter lengths of clear bole than the nonreleased trees, but the difference was significant only for codominant red oak and intermediate yellow-poplar trees (Table 5). At the end of the 5-year measurement period, yellow-poplar and black cherry trees that were in the dominant and codominant crown position before release averaged about 13 feet of clear bole; red oak averaged about 12 feet, and sugar maple averaged less than 8 feet.

Crop trees damaged by grapevines

Because grapevines can seriously damage or kill young hardwood trees (Trimble 1974b), we separated the damaged and undamaged crop trees. Although the sample was too small for statistical analysis, certain trends were evident. About 34 percent (64) of the crop trees that were

Table 4.—Average diameter growth of study trees before and 5 years after treatment

Crown class before treatment	Treatment	Crop trees living at 14 years	Dbh	
			At 9 years	At 14 years
		Number	*Inches*	
		SUGAR MAPLE		
Dominant	Release	7	1.3	2.6
	Nonrelease	8	1.4	2.4
Codominant	Release	11	1.2	1.9
	Nonrelease	5	1.1	1.6
Intermediate	Release	13	.9	1.4
	Nonrelease	6	.9	1.4
		RED OAK		
Dominant	Release	2	1.3	2.6
	Nonrelease	10	1.2	2.3
Codominant	Release	16	1.1	2.1*
	Nonrelease	16	1.0	1.7
Intermediate	Release	14	.8	1.3
	Nonrelease	10	.8	1.0
		YELLOW-POPLAR		
Dominant	Release	5	1.1	3.4
	Nonrelease	4	1.1	3.5
Codominant	Release	5	.9	3.1*
	Nonrelease	7	.7	1.9
Intermediate	Release	5	.8	1.7*
	Nonrelease	11	.6	1.1
		BLACK CHERRY		
Dominant	Release	4	2.1	4.6
	Nonrelease	7	1.3	3.0
Codominant	Release	4	1.2	2.6
	Nonrelease	11	1.0	2.0
Intermediate	Release	3	.8	1.5
	Nonrelease	5	.7	1.1

* $P<0.05$

living 5 years after treatment had been severely damaged (Table 6).

The height growth of crop trees damaged by grapevines was lower than that of undamaged crop trees 5 years after treatment. The weighted average height growth for damaged and undamaged trees was: sugar maple: damaged, 4 feet; undamaged, 8 feet; red oak: damaged, 5 feet; undamaged, 10 feet; black cherry: damaged, 9 feet; undamaged, 13 feet. Yellow-poplar was not included in Table 6 because only five trees were damaged.

The effects of grapevines on diameter growth were not as evident as those on height growth; however, in most instances, diameter growth was higher for the undamaged trees. This is particularly true for the trees that already were dominant when they were released.

Because grapevines reduced height growth, the average crown position was also reduced.

Some trees died directly from grapevine damage; 14 years after clearcutting, 70 percent of the crop trees had grapevines in their crowns, and the stand averaged about 1,000 grapevine stems per acre.

SUMMARY

Five years after treatment, 21 of 274 study trees (8 percent) had died; more important, only 64 of these 274 trees (23 percent) were still potential crop trees.

Release did not prevent crown-class regression. Forty of the 54 originally dominant crop trees (22 released; 32 nonreleased) and 21 of the 81 originally codominant crop trees (40 released; 41 nonreleased) were still dominant or codominant 5 years after treatment. But the remaining stems had regressed to intermediate or overtopped crown positions, or had died.

Grapevines had seriously damaged about one-fourth of the 253 study trees that were still alive 14 years after clearcutting; but 70 percent of the study trees had grapevines in their crowns.

Table 5.—Average length of clear bole of study trees before and 5 years after treatment

Crown class before treatment	Treatment	Crop trees living at 14 years	Length of clear bole	
			At 9 years	At 14 years
		Number	*Feet*	
		SUGAR MAPLE		
Dominant	Release	7	4.2	8.0
	Nonrelease	8	3.0	9.4
Codominant	Release	11	3.7	6.8
	Nonrelease	5	2.7	4.9
Intermediate	Release	13	3.8	6.3
	Nonrelease	6	4.3	6.6
		RED OAK		
Dominant	Release	2	7.3	14.0
	Nonrelease	10	5.3	12.5
Codominant	Release	16	5.1	8.8*
	Nonrelease	16	4.9	11.3
Intermediate	Release	14	5.3	9.1
	Nonrelease	10	4.0	8.0
		YELLOW-POPLAR		
Dominant	Release	5	5.3	12.2
	Nonrelease	4	4.6	15.1
Codominant	Release	5	5.3	12.3
	Nonrelease	7	5.1	13.3
Intermediate	Release	5	5.5	6.7*
	Nonrelease	11	4.8	9.0
		BLACK CHERRY		
Dominant	Release	4	4.9	12.7
	Nonrelease	7	6.0	12.6
Codominant	Release	4	6.4	16.1
	Nonrelease	11	4.7	13.3
Intermediate	Release	3	3.8	8.6
	Nonrelease	5	4.8	7.8

* $P<0.05$

Table 6.—Effect of grapevine damage on average height and diameter growth of study trees 5 years after treatment

Crown class before treatment	Treatment	Study trees		Height growth at 14 years		Dbh growth at 14 years	
		Undamaged trees	Seriously damaged trees	Undamaged trees	Seriously damaged trees	Undamaged trees	Seriously damaged trees
		Number		*Feet*		*Inches*	
			SUGAR MAPLE				
Dominant	Release	7	10	10.2	6.2	1.3	1.1
Codominant	Release	11	5	9.3	3.8	.7	.6
	Nonrelease	5	4	6.5	.5	.5	.5
Intermediate	Nonrelease	6	3	6.4	2.4	.4	.2
			RED OAK				
Dominant	Release	2	3	10.4	3.2	1.4	.7
	Nonrelease	10	3	10.7	7.0	1.1	.8
Codominant	Release	16	3	8.8	3.6	1.0	1.3
	Nonrelease	16	4	10.0	6.1	.7	.8
			BLACK CHERRY				
Dominant	Release	4	4	15.6	10.2	2.5	1.6
	Nonrelease	7	5	13.3	9.4	1.7	1.6
Codominant	Release	4	3	16.0	8.2	1.4	1.4
	Nonrelease	11	5	10.1	6.8	1.0	1.0

CONCLUSIONS

On the basis of our results, we conclude that it is inadvisable to release 9-year-old sugar maple, red oak, yellow-poplar, or black cherry crop trees on a good site (site index 70 for northern red oak). Release did not significantly improve height or diameter growth or length of clear stem, nor prevent crown-class regression during the 5-year period after treatment.

To reduce the risk of grapevine damage to crop trees, grapevines should be cut at ground level throughout a stand. But we certainly do not recommend killing all grapevines, because they are a valuable asset to wildlife. Land managers need information from wildlife personnel to achieve a compromise between wildlife and timber.

When released, dominant and codominant study crop trees averaged about 16 feet in height. We believe that forest managers should wait until dominant and codominant crop trees are about 25 feet tall before releasing them.

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8 p. (U. S. Dep. Agric. For. Serv. Res. Pap. NE-394).

Crop trees were released in an Appalachian hardwood stand (site index 70 for northern red oak) that had been clearcut 9 years earlier. We released 134 yellow-poplar, red oak, black cherry, and sugar maple stems of seedling origin to a 5-foot radius around the bole of each study tree; 140 comparable stems were not released. These trees were dominant, codominant, or intermediate, and all treated trees were released to a dominant crown position. On the basis of results 5 years after treatment, we do not recommend releasing such trees by the methods used in this study.

Keywords: Crop-tree release, Appalachian hardwoods, young even-aged stands, grapevines.

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ODC 245.1:176.1 *Prunus serotina*

by Ted J. Grisez

Pruning Black Cherry in Understocked Stands

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1978

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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ABSTRACT

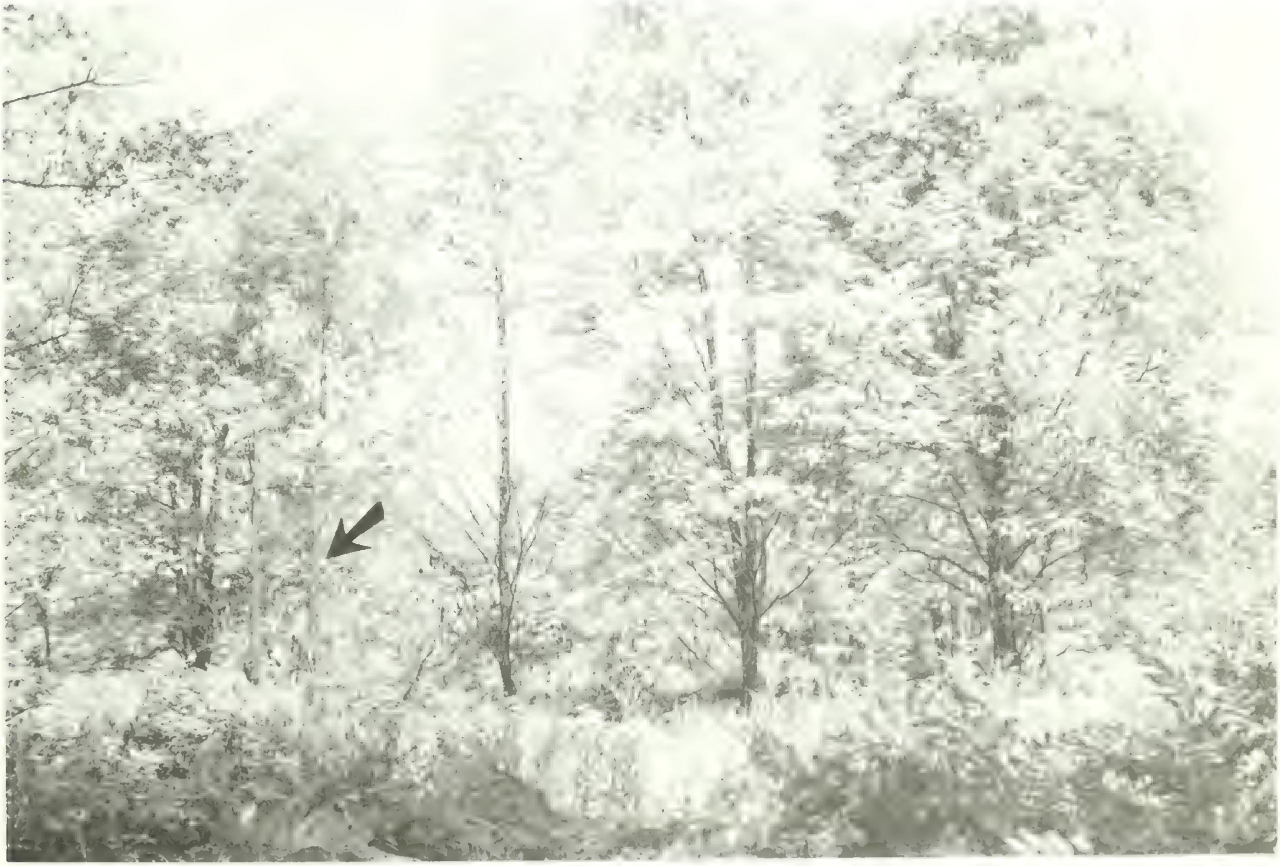
Black cherry trees 4 to 6 inches in diameter at breast height (dbh) with live crown ratios ranging from 73 to 92 percent were pruned to 25, 50, or 75 percent of tree height or were left unpruned. Most trees can be pruned to 50 percent of tree height in one operation. Trees that have large crowns and that are fully exposed on the southwest side should be pruned less severely. Pruning to 75 percent of tree height caused excessive epicormic branching, poor diameter growth, and serious cambium necrosis.

BLACK CHERRY (*Prunus serotina* Ehrh.) is one of our most valuable hardwood tree species, and its usefulness, especially for veneer, depends largely on the amount of clear, knot-free wood that can be produced. Since it is a fairly intolerant species, black cherry prunes itself well in stands that are well stocked with a mixture of species.

But there are thousands of acres of understocked black cherry stands on the high Allegheny Plateau. Most of these stands contain scattered, young, fast-growing, and well-formed trees that are heavily branched because of open growing conditions (Fig. 1). Attempts have been made to regenerate such stands, but regeneration is difficult unless conifers are planted. Pruning provides a means of salvaging these trees and developing stands of higher value. There are likely to be other opportunities for artificial pruning where trees are planted at wide spacings, and where natural regeneration after clearcutting is inadequate, resulting in wide spacing.

Little work has been done on pruning black cherry. Zeedyk and Hough (1958), reporting on a study at the Kane Experimental Forest in northwestern Pennsylvania, concluded that pruning black cherry is a promising silvicultural practice. Pruning was done in a "somewhat open" 13-year-old stand that had been weeded. Trees averaged 2.6 inches in diameter at breast height (dbh), and were pruned to a height of 8

Figure 1.—Black cherry trees in an understocked stand on the Allegheny National Forest. The arrow indicates a study tree that has been pruned.



feet. There is no record of how much crown was removed in pruning. The canopy closed well before the end of the study at age 32. Decay and epicormic branching were not serious. Cambium necrosis did not occur, and all flush-cut black cherry pruning wounds healed in 5 years. Pruned black cherry trees grew an average of 0.338 inches in dbh per year for 19 years, or about 1 inch in 3 years.

A study of pruning in northern hardwoods in Wisconsin included a few black cherry trees, but not enough for separate analysis. However Stoeckeler and Arbogast (1948) reported that pruning cuts on these black cherry trees healed with a minimum of decay.

This study was initiated in 1962 to determine the effects of different intensities of pruning on the growth and quality of open-grown black cherry trees. Three-year results reported by Grisez (1967) have been reaffirmed; they have been supplemented by 10 years of growth records and by examination of dissected stem sections.

METHODS

Scattered black cherry trees in five areas near Marienville, Pa., on the Allegheny National Forest were selected for pruning. The trees were 4 to 6 inches in diameter, reasonably straight, free of forks, and they had live crown ratios ranging from 73 to 92 percent (average of 83). Heights ranged from 23 to 46 feet (average of 35); most trees were 22 to 29 years old.

Open-grown trees provided a severe test of pruning—to prune trees with large crowns and some large live branches. These understocked black cherry stands occupy many of the broad, shallow valleys near the heads of streams. These are areas that never regenerated well—in contrast to the slopes and uplands—after extensive logging and fires that occurred until about 45 years ago. A mixture of grasses, sedges, composites, and other herbs form a generally complete ground cover.

A total of 48 trees were studied—16 trees each in the 4-, 5-, and 6-inch diameter classes. Four trees in each diameter class were randomly assigned to one of four treatments. The treatments and the percentage of live crown removed were:

Treatment	*Percentage of live crown removed*	
	(average)	*(range)*
Not pruned	0	0
Pruned to 25 percent of total height	13	0-19
Pruned to 50 percent of total height	42	37-49
Pruned to 75 percent of total height	71	66-75

The trees were pruned in July and early August, 1962. Trees were diagramed to show: (1) branch locations on each of four faces; (2) whether branches were live or dead at the time of pruning; (3) whether they were removed by pruning or not; and (4) their diameters to the nearest half inch just above the basal swell. The first 17 feet of all trees were diagramed, as were additional heights on trees pruned higher than 17 feet. In all, 988 branches were removed and were observed; 513 unpruned branches also were observed. The 585 live branches that were removed averaged 1.0 inch in diameter; the dead branches removed averaged just over 0.6 inch. An average of 1.5 branches were removed per foot of clear length achieved. No time records were kept.

The diameter at breast height and the total height of each tree were measured at the time of pruning; trees of all treatments averaged 5.1 inches in dbh before pruning. Diameters were remeasured each year for 10 years, ending in 1972, and heights were remeasured after 2 and 4 years. Pruning wounds and diagramed branches were observed each year to determine dates of wound healing and natural pruning.

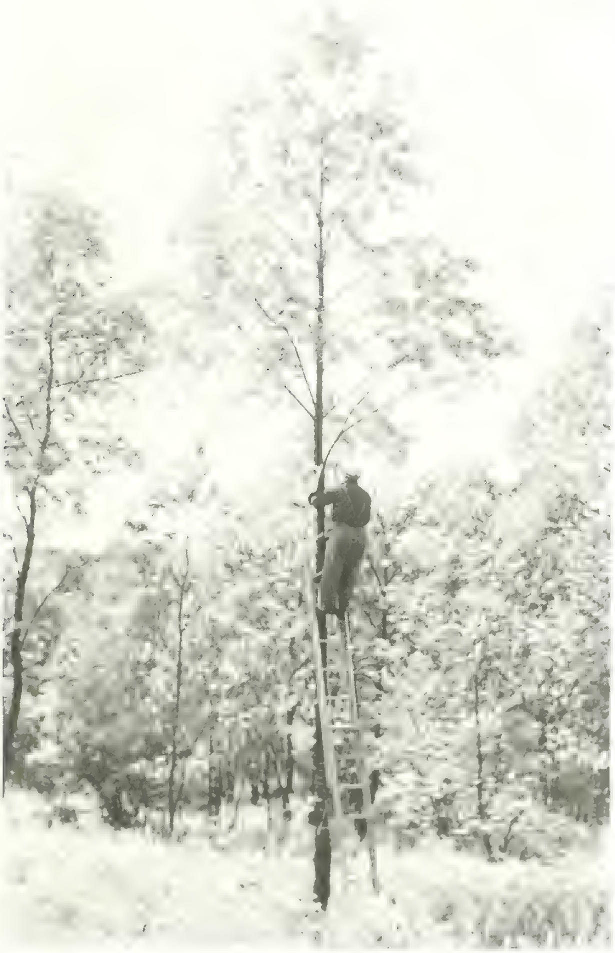
Epicormic branches on the first 17 feet, or up to the height pruned if higher than 17 feet, were observed each year for 6 years and again in 1972. The number and estimated average length of epicormics were recorded by 4-foot bole sections. All of these records were made about the same time each year—in late July or early August. In November 1974, 11 trees were cut to examine a sample of pruning wounds covering the size range of limbs, both live and dead at the time of pruning.

RESULTS

Pruning methods. Extension ladders of light metal proved to be better than a pole pruner for the higher limbs. We used a 16-foot ladder for trees pruned to 50 percent of their height (Fig. 2), and a 40-foot ladder for those pruned to 75 percent. We had used a pole pruner at first, but it was difficult to apply pressure, to handle the saw in whorls of branches, or to saw close and parallel to the stem. A pruning saw mounted on an ax handle was effective for limbs within reach from the ground.

Smooth young black cherry bark is susceptible to wounding. At first the flat step of the metal ladder caused wounds that resulted in extensive necrosis on trees pruned to 75 percent, but this accidental wounding was prevented by padding the ladder. The cambium was also killed where sawteeth dragged against the bark.

Figure 2.—A black cherry tree that is 6 inches in dbh is pruned to 50 percent of its height from a 16-foot extension ladder.



Diameter growth at breast height. The diameter growth was significantly reduced by the most severe treatment—pruning to 75 percent of total height; there was a slight, but nonsignificant, reduction in the 50-percent pruning treatment. The diameter growth rate of trees in the 50-percent treatment caught up to the unpruned trees and those pruned to 25 percent by the third year after pruning; the growth rate of trees in the 75-percent treatment caught up in about 7 years (Fig. 3).

Differences in *annual* growth rates due to treatments were no longer significant after the fourth year. After 10 years, the differences in *total* diameter growth were still significant at the 5 percent level. These differences were due primarily to the 75-percent treatment.

The recovery of annual diameter growth in the trees pruned to 75 percent was made possible by the epicormic branching which, in some cases, must have matched the amount of crown removed by the middle or latter part of the study.

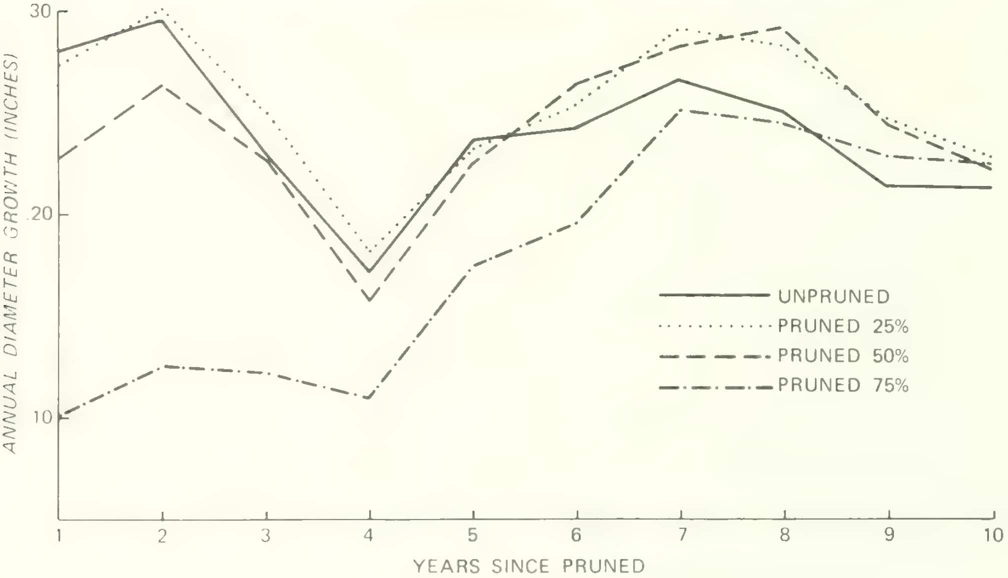
A deficiency in summer rainfall was probably responsible for a 25-percent decrease in diameter growth rate in the 1966 measurements (Fig. 3). Precipitation during May, June, and July, the three months preceding diameter measurement, was 47 percent below normal.

Total 10-year diameter growth, by treatments, was:

Pruning height (percent)	*10-year growth in dbh (inches)*
0	2.39
25	2.54
50	2.40
75	1.77

Height growth. Height growth on the trees in the 50- and 75-percent pruning treatments was slightly better in the 2 years after pruning than it was on the other trees, but the differences were not significant at the 5 percent level; differences were even less after 4 years. Height measurements were not made after 4 years. Height growth by pruning treatment (in feet) for the first 2 and 4 years after pruning were:

Figure 3.—Annual diameter growth by treatment and year.



Years	*Percent of height pruned*			
	0	*25*	*50*	*75*
1962-64	2.0	2.1	2.7	2.7
1962-66	3.8	4.5	4.3	4.8

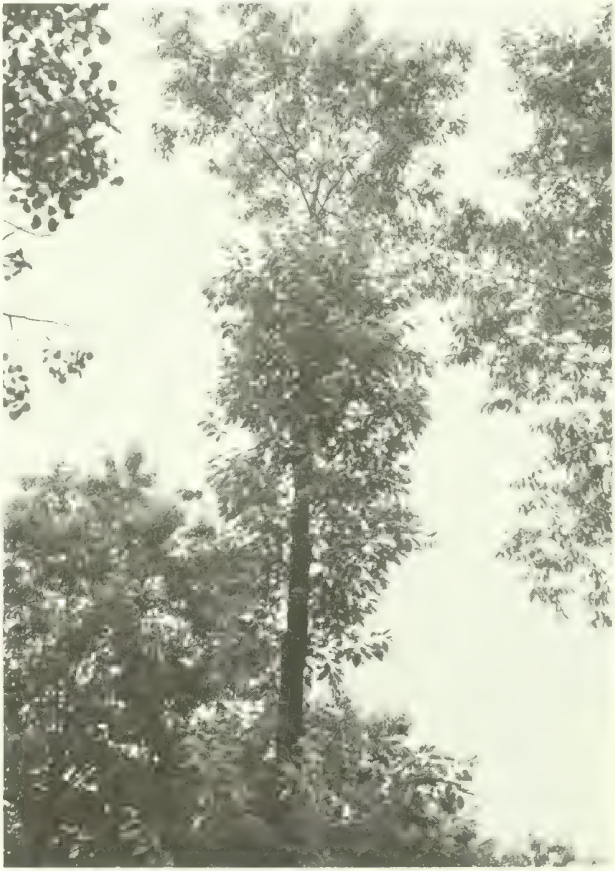
Epicormic branching. Sprouting on the boles of the most heavily pruned trees was immediate and profuse (Fig. 4). After 1 year, the average tree in the 75-percent treatment had 35 epicormics that averaged nearly 2 feet in length. Sprouting was light on the 50-percent trees, and was negligible on the others (Table 1).

The numbers of epicormics on trees pruned to 75 percent declined steadily during the study

Table 1.—Average number of epicormic branches per tree on the first 17 feet of unpruned trees and the pruned portions of others 1, 5, and 10 years after pruning in 1962

Pruning height	Years since pruning		
	1	5	10
Percent			
0	0.3	0.6	0.4
25	.0	.4	.4
50	1.9	4.7	2.2
75	35.2	25.7	12.6

Figure 4.—Thirty-six epicormic branches were alive 4 years after this tree had been pruned to 75 percent of its height.



(Table 1). Epicormics in the 50-percent treatment increased somewhat but then declined, while those on other trees remained at low levels. Even the unpruned trees had some epicormics (Table 1), as did the unpruned portions of the first 17 feet of trees pruned to 25 percent. Surviving epicormics continued to grow in length.

Individual trees varied greatly in the numbers of epicormics that were produced and that survived. Trees in the 75-percent treatment had from 0 to 24 surviving sprouts at the end of the study, and trees in the 50-percent treatment had from 0 to 7 each.

Pruning to 25 or to 50 percent increased the clear length of bole from about 3 to 10 feet (Table 2). The trees pruned to 50 percent had an average of only 2 epicormics on the first 18 feet, while those pruned to 25 percent were very limby (unpruned) above 9 feet. Even if the epicormics on the trees pruned to 50 percent continue to live, the grade of butt logs from these trees will be greatly improved.

Exposure, and possibly heredity, influenced the number of epicormic sprouts. For example, among trees pruned to 50 percent, those with 0 or 1 sprout had point densities around them that averaged 38 square feet per acre at the end of the study—as measured with a 25-factor prism, compared to only 8 square feet of competitors around trees with 2 or more epicormics. Thus the most serious epicormic branching was associated with very low stand densities.

There was no correlation between the number of epicormics and the number or size of the branches removed. Despite an apparent correlation for some trees on which vigorous sprouting occurred where large live limbs had been pruned, other trees did not react this way. One completely open-grown tree that was pruned to 50 percent of its height by removing an above-average number and size of branches remained free of epicormics (Fig. 5). Since this characteristic may be hereditary, the tree was included in the Black Cherry Tree Improvement Program.

Table 2.—Average clear lengths before pruning, after pruning, and 10 years later (in feet)

Pruning height	Total height in 1962	Clear length in 1962		Clear length in 1972
		Before pruning	After pruning	
Percent				
0	34.3	3.9	3.9	4.0
25	35.0	3.4	9.2	9.4
50	34.0	3.5	18.0	10.4
75	36.4	3.0	27.6	8.2

There were more epicormics on the sunny southwest faces of the trees than on the other faces at the end of the study. The fewest numbers of epicormics were on the shaded northeast sides. These differences were significant at the 5 percent level. The percentages by face for 16 trees were:

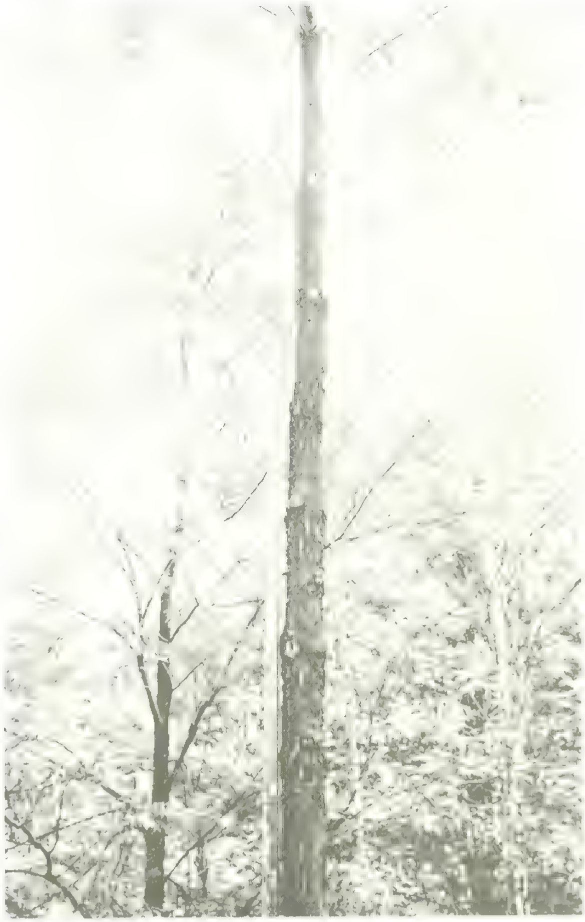


Figure 5.—This fully exposed tree was pruned to 50 percent of its height 3 years earlier by cutting 18 live limbs up to 2 inches in diameter, and 8 others. The tree remained free of epicormics.

Face	*Percentage of all epicormics*
SW	39
NW	28
SE	23
NE	10

Percentages connected by lines were not significantly different.

Wound healing. Most of the wounds on trees in the 25- and 50-percent treatments healed during the first 4 years after pruning (Table 3). Except for two cases where large necrotic areas developed and prevented healing, all but one scar on the 25- and 50-percent treatments healed by 1971. The two largest wounds—4 x 7- and 3 x 5-inch scars where 2.5-inch limbs were removed—were closed by 1968.

Most of the wounds on the trees pruned to 75 percent also healed during the first 4 years, but 11 of the 539 wounds on these trees were not healed after 10 years; this was caused by the reduced diameter growth rates at points low on the stems.

Pruning wounds healed fastest on the trees pruned to 50 percent; 70 percent of the wounds on these trees were closed after 4 years (Fig. 6).

Figure 6.—Wound healing 4 years after pruning to 50 percent of tree height. The three branches were 5 to 7 feet aboveground. The lower branch was 1 inch in diameter; the others 1.5. The upper branch was live; the others were dead when pruned.

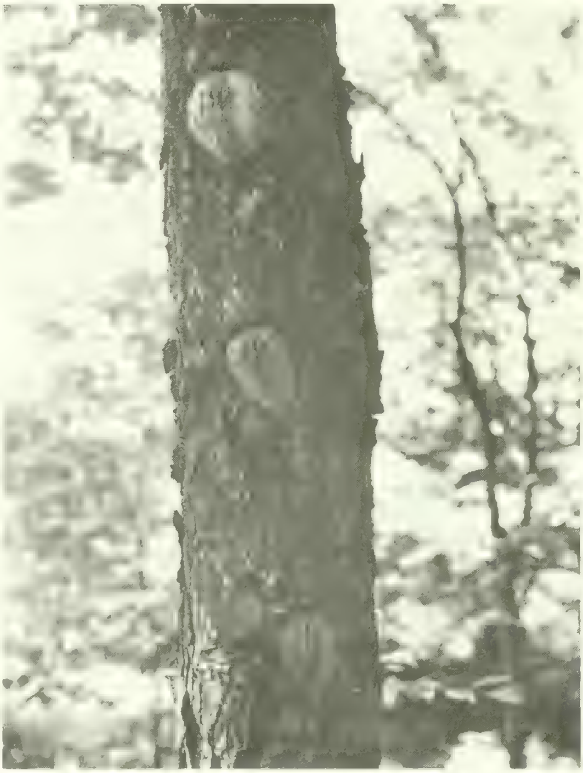


Table 3.—Accumulated proportion of pruning scars healed, by branch size and year, for the 25- and 50-percent treatments combined (in percent)

Branch diameter	Years since pruning									
	1	2	3	4	5	6	7	8	9	10
Inches										
Live branches										
0.5	6	68	88	97	97	100	—	—	—	—
1.0	—	11	47	72	88	94	96	97	100	—
1.5	—	—	8	31	58	90	96	100	—	—
2.0	—	—	—	25	75	100	—	—	—	—
2.5	—	—	—	—	—	100	—	—	—	—
Total	1	18	43	64	81	94	97	98	100	—
Dead branches										
0.5	7	38	59	78	89	96	99	100	—	—
1.0	—	7	33	59	71	83	91	97	98	98
1.5	—	—	50	67	67	83	100	—	—	—
Total	5	28	52	73	83	92	97	99	99.5	99.5
All branches	3	24	48	69	82	93	97	99	99.7	99.7

The corresponding percentages were 65 for the 25 percent treatment, and 50 for the 75-percent treatment.

Apparent differences in healing rates between live- and dead-branch wounds were actually caused by other factors. As a group, dead-branch pruning wounds healed slightly faster than live-branch wounds (Table 3) because the average size of dead branches was smaller. For a given size of branch, live-branch wounds healed faster, but this can be explained by the fact that live branches tend to be located near the tree crown where diameter growth and healing is more rapid, while dead branches are often low on the trunks.

I compared healing rates by 4-foot sections of the stems and found that significantly more wounds healed on upper stem sections by a given date than on the lower sections. There was no statistical difference in healing rates for live- and dead-branch wounds of the same size and position.

Wound healing might have been faster if the trees had been pruned in the dormant season. Marshall (1931), Roth (1943), and Phares and others (1975) recommended pruning in the late dormant season; Neely (1970) found more healing on May wounds than on July wounds. But Woessner (1972) found that more epicormic branches formed on eastern cottonwood trees pruned before or during leafing out than on those pruned after leafing out. If black cherry reacts in the same way, it would be better to prune in the summer.

Cambium necrosis. cambium necrosis was serious only on 2 of the 24 trees pruned to 25 or 50 percent. One 50-percent tree with much poorer vigor than the others had necrosis associated with 5 pruning wounds. All but 1 of these healed with little or no decay. In this case the cambium between 2 pruning wounds on the southwest face died, making 1 large wound. Cambium necrosis was extensive on a second tree that was fully exposed and on which several large limbs had been pruned from the lower southwest side.

Cambium necrosis was more common and more serious on trees pruned to 75 percent of tree height. Eight of the 12 trees in this treatment had noticeable necrosis. While most of the small necrotic areas healed during the study, 4 of the 75-percent trees were ruined by extensive necrosis and resulting decay; this was caused by the close proximity of large live limbs that were removed by pruning, by accidental saw or ladder scrapes, or by sunscald. The worst necrotic areas were on the southwest sides of the trees.

Natural pruning. Pruning is especially useful where natural death and shedding of branches is slow. Records of branches not removed by pruning on the first 17 feet of the control and 25-percent treatments show the slow rate of natural pruning on these open-grown trees (Table 4). Only 7 percent of all live branches at the start of the study in 1962 died, dropped off, and healed by 1972; 56 percent of the dead branches in 1962 did so. The latter percentage is fairly high because many of the branches were in the 0.5-inch class. Only 6 out of 42 (14%) of the larger dead limbs healed.

Decay related to pruning. In November 1974, we split open 46 wounds on 11 trees to check for decay; these covered the range of limb sizes pruned—0.5 to 2.5 inches. They were almost evenly divided between live and dead branches, and included both rapidly healed and slowly healed scars. Six of the 11 trees had been pruned to 50 percent of tree height; these 6 trees contained the largest limbs, and the only unhealed necrotic areas among trees in this treatment.

Frederick H. Berry, pathologist with the Northeastern Forest Experiment Station's Delaware, Ohio, laboratory, made cultures from

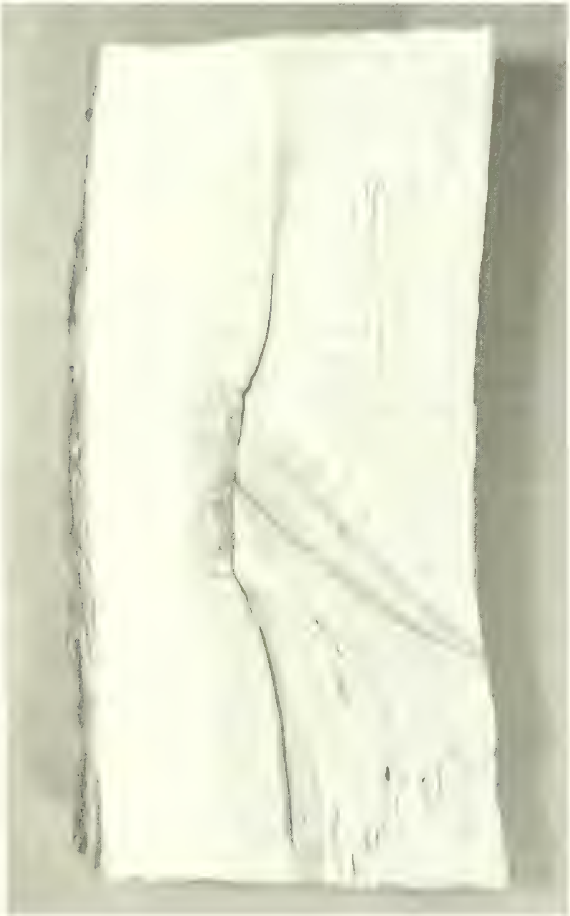
Table 4.—Number of unpruned branches on the first 17 feet of the control and 25-percent treatments that dropped off and healed in 10 years, by branch condition and size.

Branch diameter	Healed	Not healed
Inches		
Live		
0.5	14	62
1.0	4	138
1.5	0	33
2.0	0	5
Total	18	238
Dead		
0.5	114	57
1.0	6	31
1.5	0	5
Total	120	93

14 of the 25 wounds that showed at least a trace of decay. He found active decay in five wounds from three trees; in two of them, the decay was considered serious.

The fungus, *Phlebia chrysocrea* (Berk. & Curt. in Berk.) Burds., was isolated from pruning scars on two vigorous trees. Only one scar seemed to have admitted extensive decay. This was a 4- x 7.5-inch scar that resulted from cutting off a 2.5-inch limb that branched off at an acute angle. Traces of decay in five other wounds where 1.5- to 2.5-inch branches had been removed by pruning were confined in or were next to the enclosed branch stubs, and probably would not have remained active much longer. Decay found in another large pruning scar seemed to have originated at the 4- x 7.5-inch scar.

Figure 7.—Most pruning wounds were sound; this wound, the result of pruning a 1-inch dead branch, healed in 2 years.



In the second tree with advanced decay, *Coriolus versicolor* (L. ex Fr.) Quel. was active in one of six samples from a small, well-exposed tree of very poor vigor. There was extensive decay associated with a large necrotic area on the southwest face that began where two pruned branches had been close together. The active fungus apparently spread from this area rather than originating at the pruning wound where it was found.

Three other pruned trees that were sectioned and sampled had no active decay, and all sectioned wounds on three additional trees were sound (Fig. 7). All sectioned branch stubs on one unpruned tree were sound; those on another were sound or had inactive decay confined to the branch stubs.

Pruning should decrease the risk of decay; though there may be decay at a few of the larger pruned limbs, there is likely to be more of this decay where limbs are not removed but allowed to grow larger and die naturally.

SUMMARY

Only the 75-percent treatment caused a significant reduction in diameter growth at breast height. After this treatment, growth was only 36 percent of that of unpruned trees the first year, but crown recovery gradually reduced the difference so that the 10-year diameter growth on the pruned trees was 74 percent of that of the unpruned trees.

Height growth was slightly, but not significantly greater for the 50- and 75-percent treatments during the first 2 years after pruning.

Trees pruned to 75 percent produced an average of 35 epicormic branches the first year after pruning; an average of 13 per tree were living after the tenth year. Epicormic sprouting was not serious on most of the trees pruned to 50 percent, and sprouting was negligible on the others. The southwest faces of the stems had more epicormics than other faces; the northeast faces had fewer.

Sixty-five and 70 percent of the pruning wounds healed during the first 4 years for the 25- and 50-percent treatments, respectively. There was no difference in healing rates for live- and dead-branch wounds of the same size and position.

On trees pruned to 25 and to 50 percent, cambium necrosis was serious on only one tree of very poor vigor, and on another where several close and large limbs were removed from the southwest side of a fully exposed tree, or where accidental wounds were made. Trees pruned to 75 percent were more sensitive to exposure and accidental wounding.

Natural pruning was very slow on these open-grown trees. Only 7 percent of all live unpruned limbs on the first 17 feet of tree stems died, dropped off, and healed in 10 years. Each of these limbs was 1 inch or less in diameter.

Active decay organisms were found in 3 of the 11 trees sampled, and decay was serious in 2 of them. Decay in one tree originated where a 2.5-inch live limb left a 4- x 7.5-inch pruning scar. The second tree with serious decay was one of very poor vigor.

CONCLUSIONS AND RECOMMENDATIONS

Pruning young black cherry trees in understocked stands can increase the quality and value of the trees.

Pruning open-grown trees to 75 percent of their heights was clearly detrimental, primarily because of the many epicormic branches generated by such severe pruning. Also, diameter growth was reduced, wound healing was somewhat slower, and cambium necrosis was more serious in these trees than in trees that received lighter pruning.

Pruning trees to 50 percent caused few problems; this treatment should be feasible for most black cherry trees. Pruning should be limited to 40 percent of total height on trees that are fully exposed on the south and west sides, if 75 percent or more of their length is in live crowns. Limbs 2 inches or more in diameter are somewhat risky to prune—decay might develop unless the trees are very vigorous.

Pruning in two stages should be practical for gaining more clear length, exposing the southwest face more gradually, if necessary, and removing any epicormics that may have sprouted.

A better job of pruning can be done from a ladder with a hand pruning saw than from the ground with a pole pruner. But care must be taken not to scrape or bruise the thin bark with the ladder or saw. Pruning cuts should be close to the stem and undercuts should be made, if necessary, to prevent bark stripping.

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Grisez, Ted J.
1978. **Pruning black cherry in understocked stands.** Northeast. For. Exp. Stn., Broomall, Pa.
9 p., illus. (U.S. Dep. Agric. For. Serv. Res. Pap. NE-395)

Black cherry trees 4 to 6 inches in diameter at breast height (dbh) with live crown ratios ranging from 73 to 92 percent were pruned to 25, 50, or 75 percent of tree height or were left unpruned. Most trees can be pruned to 50 percent of tree height in one operation. Trees that have large crowns and that are fully exposed on the southwest side should be pruned less severely. Pruning to 75 percent of tree height caused excessive epicormic branching, poor diameter growth, and serious inner bark and cambium necrosis.

245.1:176.1 *Prunus serotina*

Keywords: Pruning, black cherry, *Prunus serotina*, diameter growth, epicormic branches, healing rate, natural pruning, fungi, cambium necrosis.

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ODC 411--145.7 x 18.77 *Lymantria dispar*

by J. D. Wollam, W. G. Yendol, and F. B. Lewis

Evaluation of Aerially-Applied Nuclear Polyhedrosis Virus for Suppression of the Gypsy Moth, *Lymantria dispar L.*

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ABSTRACT

Single and double applications of the nuclear polyhedrosis virus of *Lymantria dispar* L. were evaluated for suppression of gypsy moth infestations in Pennsylvania. The virus material, purified by isopynic centrifugation, was applied by air at the rate of 2.47 x 10^{12} polyhedral inclusion bodies per hectare. Two formulations of the virus were evaluated: one consisted of 1.12 kg of IMC-90001®, 0.88 liter of Chevron spray-sticker®, 4.67 liters of CIB®, and 13.14 liters of water/ha; the other was 9.34 liters of Sandoz virus adjuvant® and 9.34 liters of water/ha.[1] Application of the virus provided foliage protection, population reduction, and increased the number of virus-infected larvae. No consistent differences were observed between the two formulations, and the second application did not enhance treatment effects. In the following year, larval emergence from egg masses was significantly lower in the virus-sprayed areas than in the untreated population.

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[1] The use of trade, firm, or corporation names is for the convenience and information of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service or Pennsylvania State University of any product or service to the exclusion of others that may be suitable.

INTRODUCTION

THE NUCLEAR polyhedrosis virus (NPV) of *Lymantria dispar* L. is a naturally occurring disease agent that induces epizootics in gypsy moth populations as their densities increase (Campbell 1963a). In laboratory investigations the virus was found to be most pathogenic to early instar larvae (Doane 1967; Magnoler 1974a). Determinations of the relative virulence of purified and nonpurified NPV preparations have produced conflicting results (Magnoler 1968a; Rollinson and Lewis 1973; Yendol and Hamlen 1973) and tests with different geographic isolates of the virus have shown the Hamden (Connecticut, USA) strain to be one of the most virulent (Magnoler 1970; Rollinson and Lewis 1973; Vasiljevic and Injac 1973).

Preliminary field studies utilizing ground (Magnoler 1967, 1968a, b, 1974b; Rollinson et al. 1965) and air (Yendol et al. 1977) applications have indicated that NPV is effective in causing larval mortality, protecting foliage, and reducing egg mass densities.

MATERIALS AND METHODS

The experimental site was in a gypsy-moth-infested area in Centre, Union, Clinton and Lycoming Counties, Pennsylvania. Fifteen treatment plots, 14.2 ha (379.0 x 379.0 m) in size, were established. The dominant tree species in the area were oaks, *Quercus* spp., 10 to 18 m in height. Ten 0.01 ha subplots (11.3 m diam.) were established in each plot for data collections.

A randomized complete block design was used to evaluate three replications of four treatments and a control. Gypsy moth population density was used as the criterion for the block design.

The virus material used was laboratory-produced gypsy moth NPV, Hamden isolate, purified by isopynic centrifugation in a 'K' rotor at the Atomic Energy Commission facility, Oak Ridge, Tenn. This virus preparation was applied by air at the rate of 2.47 x 10^{12} polyhedral inclusion bodies (PIB) per hectare per treatment.

Two commercial adjuvant-extending materials were evaluated with the virus. One formulation (the CIB formulation) consisted, for each hectare, of 1.12 kg of IMC-90001®, 0.88 liter of Chevron® spray sticker, 4.67 liters of CIB molasses material, and 13.14 liters of water. The other formulation (the SVA formulation) tested was Sandoz virus adjuvant® at the rate of 9.34 liters of adjuvant plus 9.34 liters of water per hectare. One and two applications of the virus with each adjuvant system were evaluated.

The initial spray date was determined by two factors: when at least 50 percent of the gypsy moth larvae were in the second instar and when at least 50 percent leaf expansion had occurred on the white oaks, *Q. alba* L. The first application was made either May 26, 27, or 28, 1975, and the second on June 2, 1975, to all plots designated for a second application. All spraying was conducted between 1530 and 1930 hours. A 450 hp Grumman AgCat®, equipped with a standard boom and six Beecomist® spinning nozzles (Model 275) with 80- to 100-micrometer perforated metal sleeve assemblies was used to apply the spray at 18.7 liters of finished spray per hectare.

Treatments were evaluated on the basis of pre- and posttreatment egg mass numbers, larvae and pupae situated on or under burlap bands, larval and pupal collections, defoliation estimates, spray deposit, and bioassay.

The number of gypsy moth egg masses was determined by a method similar to that of Connola et al. (1966). Prespray egg mass densities ranged from 919 to 4920 egg masses per hectare. Evaluation of treatments was based on three population density levels: low—919 to 1344 egg masses per hectare, intermediate—1670 to 2282 egg masses per hectare, and high—3053 to 4920 egg masses per hectare. Numbers of egg masses were determined in November 1975, after the leaves had fallen.

Burlap bands were used to obtain data on relative densities of gypsy moth larvae and pupae, and for estimating the mortality from the virus in treated and untreated populations. Fifty oaks in each plot were banded as described by Yendol et al. (1973). All larvae and pupae under or on the burlap or within 7.62 cm below the band were counted. Estimates of larval density and of the incidence of virus in larvae and pupae were obtained on June 12, 13, and 18. Numbers of viable pupae and sex ratios were determined on July 29.

Progress of the virus disease in each plot was monitored by collecting gypsy moth larvae: 100 were collected from each plot before it was sprayed and at weekly intervals thereafter. These larvae were returned to the laboratory and maintained in groups of 10 on washed oak foliage at 21 to 26°C with a variable photoperiod for 8 to 9 days. Dead larvae were examined to confirm the presence of NPV.

Defoliation in each subplot was usually estimated in 10 percent increments at the cessation of larval feeding.

White oil-sensitive spray cards were used to confirm treatment coverage in each plot. Cards were positioned on 0.3-m wire holders at ground level under an opening in the forest canopy in or near each subplot. They were collected immediately after spraying.

The residual activity of each virus formulation was evaluated from foliage samples from virus-treated and untreated plots. Three samples were collected from each treatment. Sequential sampling of foliage was initiated when it was sprayed and continued 1, 2, 3, 5, 7, 9, 11 and 13 days after spraying of the single-application plots. Plots that were sprayed twice were sampled when sprayed and 1, 2, 3, 5, and 7 days after each application. Untreated areas were sampled each time foliage was collected in treated areas. Samples were taken at midcrown at cardinal directions selected on a random basis.

Egg masses collected near the experimental site were prepared according to a method described by Yendol et al. (1973). Upon eclosion, larvae were transferred to artificial diet (ODell and Rollinson 1966) and allowed to feed until needed for the bioassay. Residual virus was bioassayed using second-instar gypsy moth larvae (4-6 mg). Leaf material from each sample area was placed in five 16 oz. containers. Ten larvae were placed in each container and maintained at 21 to 26°C. Dead larvae were removed daily and examined for NPV.

A second-year evaluation of treatment effects on the subsequent generations was begun in April 1976. Larvae collected, larval and pupal populations under burlap bands, egg masses collected, and estimated defoliation were the parameters evaluated.

Unpaired t-tests using unpooled variances were used to analyze the data from burlap-band determinations and defoliation. This technique was employed because Bartlett's tests indicated heterogenous variances among the plots. Treatments at each density were analyzed separately because of highly significant ($p < 0.01$) interactions determined by the analysis of variance.

RESULTS AND DISCUSSION

Burlap-band determinations

Examination of burlap bands on June 12 and 13 indicated that some of the virus treatment plots had significantly fewer live larvae than the controls (Table 1). The percentage of NPV-killed

Table 1.—Mean numbers of gypsy moth larvae recovered (per cm of burlap) after application of NPV to plots with different population densities

Treatment	Recovered June 12, 13			Recovered June 18		
	Low density	Intermediate density	High density	Low density	Intermediate density	High density
Control	0.121a b	1.375a	1.393a	0.272a	3.570a	6.433a
SVA, 1 application	0.048a	0.259b	1.154a b	0.122b	0.215b	2.656c
SVA, 2 applications	0.175b	2.609a	1.280a b	0.320a	1.278c	2.656c
CIB, 1 application	0.083a b	0.048c	0.934b	0.061c	0.048b	1.570d
CIB, 2 applications	0.100b	0.301b	0.647c	0.052c	0.437e	0.305b

Means based on 50 burlaped oaks per plot. Means in the same column not followed by the same letter are significantly different at the 1% level (unpaired t-test using unpooled variances).

Table 2.—Estimated incidence of virus-caused mortality (in percent) in gypsy moth populations of different densities treated with NPV

Treatment	Recovered June 12, 13 [a]			Recovered June 18 [b]		
	Low density	Intermediate density	High density	Low density	Intermediate density	High density
Control	0.00a	0.38a	4.53a	0.00a	6.49a	11.55a
SVA, 1 application	8.84a	4.26a b	5.80a	44.77b	34.87b c	48.54b
SVA, 2 applications	10.51a	8.70b	21.38b	48.50b	36.51b c	52.79b
CIB, 1 application	5.56a	26.93a b c	19.76b	49.82b	56.40b	21.49c
CIB, 2 applications	1.61a	21.01c	3.81a	41.49b	27.69c	14.25a c

Means in the same column not followed by the same letter are significantly different at the 1% level (unpaired t-tests using unpooled variances).

[a] Means based on 19-50 burlaped oaks/plot (number of observations/plot varied because some trees had no larvae).

[b] Means based on 28-50 burlaped oaks/plot (number of observations/plot varied because some trees had no larvae).

larvae also increased significantly, compared with the controls (Table 2). On June 18, estimated larval populations in virus-treated plots were significantly lower than in the controls, except in the low-density double-SVA treatment. The virus-treated plots, except the high-density double-CIB application, had significantly higher virus-caused mortality than the controls. This delayed appearance of virus mortality in a treated population was also reported by Rollinson et al. (1965) and Magnoler (1974b).

In general, population was reduced and virus incidence increased when NPV was applied. Plots that received a single application showed as much and sometimes more population reduction than those that received a double application. The one exception was in the high-density CIB plots. Estimated virus incidence also indicated that single applications were as effective as double applications. In the intermediate-density CIB plots, the single application produced significantly more NPV-killed larvae than the double application. The SVA plots were more consistent in virus incidence than the CIB plots.

Collections of larvae

In gypsy moth larvae collected before spraying, mortality from NPV ranged from 0 to 5 percent among the 15 treatment plots (Fig. 1). In the first larvae collected after spraying, virus incidence remained low in the untreated areas, while all treated plots showed substantial increases in the number of virus-killed larvae. Virus mortality in the untreated area with low population density remained low throughout the experiment, but virus mortality continued to increase in the other untreated populations to a high of 70.0 percent in the third postspray collection from the area of intermediate density. In the high-density untreated area, the percentage of virus-killed larvae increased from 12.1 to 76.0 between the first and second postspray collections. Virus mortality remained high in this area for the remainder of the experiment.

The percentage of larvae killed by the virus between the first and second postspray collections increased in all treatment plots, except the high-density plot treated twice with CIB. The plots treated twice with SVA had the highest percentage of virus mortality during the third and fourth postspray collections of all densities.

Sex ratio determinations

Examination of pupal populations under burlap bands on July 29 showed significant reductions in the number of pupae in all the virus-sprayed plots except those with high population density that were treated with CIB (Table 3). In some of the intermediate and all of the high-density plots there were significant reductions in the percentage of females, as determined from pupal collections (Table 4). Two of the low-density areas had significant increases in the numbers of female pupae. Campbell (1963b) indicated that in gypsy moth populations disease was strongly selective against females, especially among late instars and prepupae. The distortion of sex ratios observed in the intermediate and high density

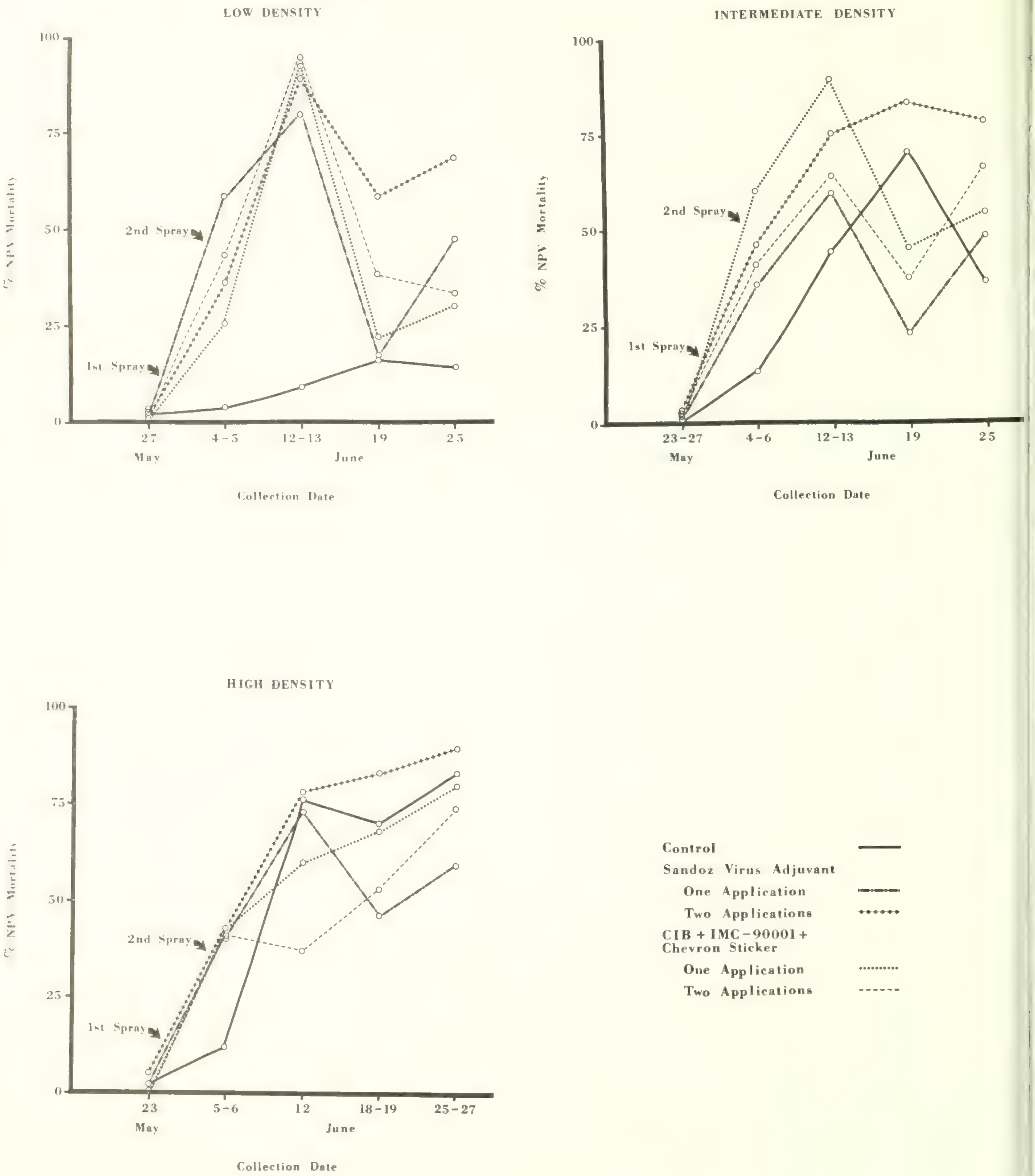

Figure 1.—Incidence of virus-caused mortality in low, intermediate, and high density gypsy moth populations after aerial applications of NPV.

Table 3.—Mean numbers of gypsy moth pupae (per cm of burlap) recovered after applications of NPV

Treatment	Population density		
	Low	Intermediate	High
Control	2.968a	7.190a	4.315a
SVA, 1 application	0.436b c	2.543b	1.049b
SVA, 2 applications	0.731b	2.562b	2.040c
CIB, 1 application	0.369b c	1.231c	4.140a
CIB, 2 applications	0.311c	1.255c	3.766a

Means based on 50 burlaped oaks/plot. Means in the same column not followed by the same letter are significantly different at the 1% level (unpaired t-test using unpooled variances).

Table 4.—Percentage of females among gypsy moth pupae in NPV-treated and control plots

Treatment	Population density		
	Low	Intermediate	High
Control	77.0*	24.0*	25.0*
SVA, 1 application	51.5	44.0	34.0*
SVA, 2 applications	45.0	14.0*	24.0*
CIB, 1 application	63.0*	37.0*	36.0*
CIB, 2 applications	51.0	56.0	27.0*

Based on a sample of 98 to 100 pupae per plot.
*Significantly different from a 1:1 ratio at the 5% level (X^2 with Yates' correction for continuity).

Table 5.—Percentage defoliation in plots with different population densities, after treatment with gypsy moth NPV

Treatment	Oaks			All species		
	Low density	Intermediate density	High density	Low density	Intermediate density	High density
Control	45.0a	95.0a	95.0a	39.0a	80.0a	88.0a
SVA, 1 application	9.0b	42.0b	27.0b	5.0b	31.0b c	16.0b
SVA, 2 applications	22.0b	81.0c	89.0c*	16.0b*	55.0b	78.0c
CIB, 1 application	7.0b	6.0d	72.0c*	5.0b	5.0d	60.0c*
CIB, 2 applications	8.0b	35.0b	84.0c*	5.0b	27.0c d	76.0c*

Means based on defoliation in ten 0.01 ha subplots/plot. Means in the same column not followed by the same letter are significantly different at the 1% level.
*Significantly different from the control at the 5% level (unpaired t-test using unpooled variances.).

untreated areas may indicate that natural virus was affecting these populations late in the season.

Defoliation estimates

There was significantly less defoliation of oaks and total defoliation in all treatment plots than in the control plots (Table 5). Plots that received a single application had as much foliage protection, or more, than those that received two applications. At the low density, no difference was observed between the formulations. However, in the intermediate-density plots a single application of the CIB formulation gave the best foliage protection to oaks. In the high density areas, a single application of SVA gave the best foliage protection.

Spray deposit cards

Spray deposits were recovered from all treatment areas. The CIB formulation had an average coverage of 10.18 droplets per square centimeter. SVA deposits had a mean of 33.01 droplets/cm^2, 3 times as much coverage. This explains, in part, the better performance of SVA.

A difference was also observed between the number median diameters (NMD) of the two formulations. The NMD was 90 μm for the SVA formulation and 140 μm for the CIB formulation. The mass median diameters (MMD) were similar for the two formulations: 320 μm for the SVA formulation and 310 μm for the CIB formulation.

Spray residue bioassay

Virus-caused mortality ranged from 63.3 to 76.0 percent when larvae were fed foliage collected during the first 24 h after the first spray application (Fig. 2). Foliage collected during the initial day after the second application produced 59.3 to 66.6 percent mortality among test larvae. Over the course of the experiment, virus-caused mortality in larvae fed foliage from unsprayed areas ranged from 4.0 to 13.3 percent.

The residual activity of the virus dissipated more rapidly after the second application than after the first application. Rainfall undoubtedly contributed; after the first spray application, there was no appreciable precipitation for 3 or 4 days—until June 1, when 7.9 mm was recorded. More than 19 mm of rainfall was recorded on June 5, 2 days after the second spray application.

After the initial reduction in virus-caused mortality in the first 2 or 3 days after spraying, the number of test larvae that died from virus remained fairly constant. Although the infectivity of the virus dissipated rapidly, the remaining activity still caused significantly more mortality than occurred among larvae fed on untreated foliage. There was an unexplained increase in virus-caused mortality among larvae that were fed foliage collected on June 3 from the area treated with a single application of SVA.

Final egg mass determination

In the low-density control area, the number of egg masses increased substantially while in the virus-treated areas it changed only slightly from prespray estimates (Table 6). Significant differences in egg mass numbers were observed between the untreated plots and the virus-

Figure 2.—Dissipation of infectivity of gypsy moth NPV applied by air to the experimental area.

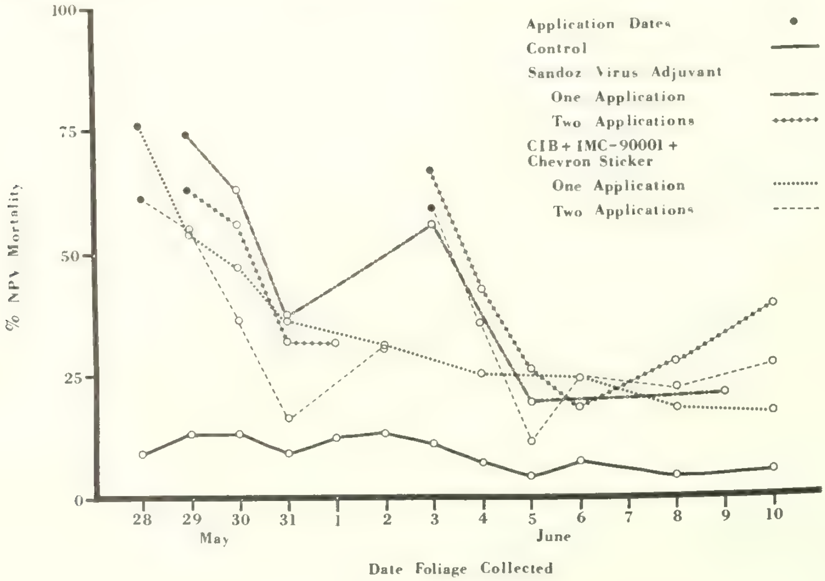

Table 6.—Estimated numbers of gypsy moth egg masses per hectare and differences (in percent) between pre- and posttreatment estimates

Treatment	Population density					
	Low		Intermediate		High	
	No. [a]	%	*No.*	%	*No.*	%
Control	7479 a	+713.8	563	− 70.5	148	−97.0
SVA, 1 application	1146 b	+ 14.8	4337	+107.0	1551	−62.4
SVA, 2 applications	968 b	− 16.3	731	− 68.0	99	−98.0
CIB, 1 application	1057 b	+ 13.8	1739	+ 4.1	3646	− 6.8
CIB, 2 applications	1314 b	− 2.2	2272	+ 0.5	4377	+43.4

Egg mass densities were estimated from counts made in ten 0.01=ha subplots per plot.

[a] Means in this column not followed by the same letter are significantly different at the 2% level (unpaired t-test using unpooled variances.

treated areas, but there was no differences among virus treatments. In the intermediate- and high-density untreated areas, the population collapsed naturally, as evidenced by the large reductions in the numbers of egg masses. The trend toward natural collapse of these gypsy moth populations was observed in larval collections as large increases in virus mortality, and in pupal collections as distorted sex ratios. The intermediate- and high-density plots that received a double application of SVA also had substantial reductions in egg masses, which appeared to be due to a natural virus epizootic. Therefore, we made no statistical analyses of the intermediate- and high-density plots.

Second year evaluation

Egg masses were collected from the low-density plots in April 1976. These plots were selected for further evaluation because there was no evidence that a natural virus epizootic had occurred in them. In some of the sprayed plots and both controls in the intermediate- and high-density areas populations had been drastically reduced by natural virus epizootics.

Egg mass size was significantly smaller in the plots that received a double application of SVA than in the control plots (Table 7). In the other virus-treated plots, the egg masses were not significantly different from those in the untreated area. Kaya et al. (1974) reported increases in the number of eggs per egg mass following *Bacillus thuringiensis* treatment, and Doane (1968) noted increases in egg mass size in gypsy moth populations treated with a chemical insecticide. It appears that treatment of gypsy moth populations with NPV does not increase egg mass size. Egg masses from all virus-sprayed plots produced significantly fewer larvae than those collected from the untreated plot.

Burlap-band estimates of larval populations made on June 18 and July 1, 1976, showed no significant differences between treated and untreated areas. But in the final determination, made on July 12, the treated plots had significantly more larvae and pupae than the unsprayed area. There was a significantly higher mortality from virus infection in the control area than in the treated plots on July 1. This indicates a natural virus epizootic in the control plots and may explain the reduced population noted on July 12.

Collections of larvae also showed more virus-caused mortality among larvae collected in the untreated areas than in the treated plots. In the final collection, NPV mortality in the plots that had had one and two applications of SVA and those that had had one and two applications of

Table 7.—Mean numbers of eggs and larvae per egg mass in the low-density plots the year after virus applications

Treatment	Eggs/mass	Larvae/mass
Control	274 a	168 a
SVA, 1 application	234 a	114 b
SVA, 2 applications	147 b	79 b
CIB, 1 application	264 a	99 b
CIB, 2 applications	260 a	90 b

Means based on 47-49 egg masses/plot. Means in the same column not followed by the same letter are significantly different at the 1% level (unpaired t-test using unpooled variances).

CIB were 86, 51, 84, and 88 percent, respectively. In the untreated area, virus mortality was 96 percent, a further indication of a developing virus epizootic.

Defoliation was estimated in July 1976 at 40 percent for all tree species in the untreated area. The plots treated with one and two applications of SVA had 14 and 7 percent defoliation, respectively; the plot that received a single application of CIB had 35 percent defoliation and the plot that received a double application had 23 percent defoliation.

Our results indicate that application of NPV to gypsy moth infestations below 4920 egg masses per hectare will provide foliage protection and population reduction while increasing virus-caused mortality, compared with untreated areas. This experiment suggests that virus applications do not improve the population quality of successive generations, as has been observed with *B. thuringiensis* and chemical insecticides; i.e., there was no increase in egg mass size, emergence from egg masses was reduced, and the virus infection was prolonged in the treated populations. Additional experiments are needed to further evaluate the field efficacy of the gypsy moth NPV, and to provide additional information on residual effects of the virus on the progeny of treated populations.

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411--145.7 x 18.77 *Lymantria dispar*

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Relationship of Species and Site Index to Habitat in the White Mountains of New Hampshire

by W. B. Leak

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Abstract

Eleven forest habitats, representing distinct differences in soil materials or substrate, were defined for areas of granitic drift in the White Mountains of New Hampshire. Beech/sugar maple/yellow birch characterize successional stands on the fine tills and the enriched or cove sites (where white ash also is common). Washed fine till and coarse till are dominated during succession by beech and birch with some red maple. Red maple is the most abundant species on sandy sediments, silty sediments, and dry compact till. Softwoods, especially red spruce and eastern hemlock, characterize successional stands on habitats representing poor drainage, shallow rock, outwash, and wet compact till. Comparative data from a previous study in old stands indicate that coarse till, fine till, and enriched sites are the only habitats where pure hardwoods are the characteristic vegetation in both successional and older stands; most of the other habitats exhibit a trend over time toward softwoods. Site index generally averages highest on habitats where hardwoods predominate and lowest on softwood habitats. Habitat classification should be used in conjunction with gradient analysis to define the relationships of forest vegetation to environmental conditions.

THE RELATIONSHIPS between forest vegetation and natural environmental factors are viewed and analyzed in two distinct ways. Sometimes, continuous changes through space in species populations and community characteristics are related to continuous changes in environmental factors or complexes of factors. This general approach is called gradient analysis (Whittaker 1967). The alternative is an attempt to classify forest vegetation into homogeneous communities associated with homogeneous levels of certain environmental factors. Much of the earliest work on forest vegetation and habitat followed some form of classification analysis, and land classification schemes still are in vogue in Canada (Rowe 1971), Australia (Mabbutt 1968), and elsewhere.

Recent major studies in the White and Green Mountains of New England have successfully employed gradient analysis. Bormann et al. (1970) showed that species and stand characteristics on the Hubbard Brook Experimental Forest in New Hampshire were strongly related to an elevational complex gradient. The only clear zonal boundary was the hardwood-boreal forest transition at about 760 m (2,500 feet) elevation, related to an increased rate of environmental change. Bormann et al. suggest that zonal or community boundaries other than this distinctive hardwood-boreal transition may be arbitrary or poorly defined. Siccama's (1974) work on Camel's Hump and three adjacent mountains in Vermont showed a similar relationship between species distribution and elevation, and provided a detailed explanation for the hardwood-boreal transition in terms of a rapid drop in the length of the frost-free season coupled with moisture and icing conditions associated with the cloud base. Descriptive work on Mt. Whiteface and Mt. Washington in the White Mountains (Leak and Graber 1974) illustrated a relationship between species and elevation similar to that shown in the previous two studies. All three studies showed that tree species exist as a series of overlapping populations similar in pattern to those described by Whittaker (1956) in the Great Smoky Mountains.

Direct gradient analysis and mathematical ordination techniques have been successfully applied to the mixed forests in the Adirondacks (Holway and Scott 1969) and the Lake States (Goff and Cottam 1967).

Clearly, one current trend in the northeastern United States is to view forest species composition as a continuum, and to analyze it by some form of gradient analysis—coupled with a recognition of the most distinct zonal boundaries such as the hardwood-boreal elevational transition. But there are two reasons why classification analysis should be recognized and used—along with gradient analysis—in the mountainous forests of New England and perhaps elsewhere as well. The first reason is utilitarian: the management of forest lands is facilitated by schemes that subdivide the land into fairly large homogeneous units. Then reasonably uniform policies and management techniques can be applied over an entire unit. Of course, we could take a recognized environmental gradient such as elevation, divide it into segments, and use segment limits to define land-unit boundaries. But the resulting units would be gradational rather than homogeneous. A management technique that worked in one part of the unit might not work in another part of the same unit.

The second reason for using classification approaches in New England forests is that certain environmental conditions tend to be discrete—changing rapidly over a short distance—rather than continuous. The primary discrete factors are those associated with glacial history and soil materials. Billings (1956) and his associates recognized and mapped more than 50 distinct types of bedrock in New Hampshire. Nearly all soils in the New Hampshire mountains are derived from glacial drift deposited about 10,000 years ago; this drift represents a composite sample of many bedrock types. Goldthwaite (1948), however, showed that New Hampshire glacial drift could be mapped with considerable detail into three distinct types representing different mineralogy, material derived from: (1) granite rocks rich in feldspar, (2) slaty schists, and (3) crystalline schists. Within any of these types of drift, Alvis and Lanier[1] have shown, glacial history and mode of deposition result in at least 14 recognized geomorphic classes and associated forest types (the list is still undergoing revision) on the White Mountain National Forest. These classes reflect continental subglaciation (glacial scouring, basal till), superglaciation (open till), alpine glaciation (scouring, deposition), glaciofluvial and fluvial action, and subsurface frost churning. This approach to geomorphic classification is being used to develop a broad system of ecologic land types on the White Mountain

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[1] Unpublished report. Region 9 Land Systems Conference, White Mt. Natl. For., Oct. 15-17, 1974.

National Forest based on land form, soil materials, and tree/shrub associations. In many cases, the types of materials associated with geomorphic classes are similar to the physical classes of parent materials locally recognized in soils classification by the Soil Conservation Service (Pilgrim et al. 1968).

Little information is published on the relationships of forest vegetation to geomorphic classes or soil materials in New England. In Ohio, however, Forsyth (1970) found that natural vegetation closely followed geologic boundaries, and the same author had some success in using vegetation to map glacial geology (Forsyth 1968). One of the main problems in relating geologic features to forest vegetation is to account for past stand history or successional stage (Hamilton and Forsyth 1972).

Preliminary work in old, undisturbed stands in the White Mountains indicated a definite relationship between tolerant species and type of soil material within glacial drift of a given mineralogy (Leak 1976). This preliminary work, which will be referred to again later, led to the current study of forest composition and productivity (site index) in successional stands, related to habitat classes based primarily on soil materials.

METHODS

During the summer of 1976, 151 temporary plots were established in the southeastern quarter of the White Mountain National Forest, all within areas of glacial drift derived from granite rich in feldspar (Goldthwaite 1948). All of these plots were located in successional stands that had developed following heavy cutting or clearcutting about 50 to 100 years before. No cultivation or heavy pasturage was evident in the soil profile on these 151 plots; however, a few additional plots were taken on such disturbed sites for comparison. All stands appeared even aged and contained a mixture of tolerant and intolerant species. Species composition and topography surrounding each plot were uniform over at least 2 to 4 hectares, except in the case of enriched sites (defined later) which sometimes were no larger than .5 hectare.

On each plot, basal area by species was estimated for all stems over 6 m (20 feet) tall using a 3-m^2 prism factor. Age at breast height (from increment cores) and total height (from several measurements with a Suunto[2] clinometer) were determined for at least one dominant tree per plot, and later converted to site index (base age 50 years) using curves from Curtis and Post (1962) and Hampf (1965). After cores with questionable age counts and periods of suppression were discarded, 122 samples remained. Aspect and approximate elevation (from topographic maps) were determined for each plot, and observations were taken on species and sizes of tree reproduction.

Toward the center of each plot, I dug at least one pit (sometimes 2 or 3) to a depth of 1 m if possible. Soil auger borings were taken around the perimeter of many plots to check on the uniformity of conditions. Major soil horizons were briefly described and measured. But the major emphasis was placed on classifying the habitat into 1 of 11 types based primarily on soil materials or substrate (B_3, C or D horizons). Most of these habitats were defined and described more fully in an earlier study of old stands (Leak 1976):

(1) **Poorly drained.**—Flat areas with heavy mottling or gray mineral soil throughout the B horizon. Substrate difficult to classify due to standing water or a shallow water table during much of the growing season.

(2) **Rock.**—Smooth tight bedrock, a matrix of sharp-angled or rounded boulders, or nearly pure grus (weathered granite) are found at depths of not more than 65 cm below the top of the mineral soil. This habitat condition often reflects glacial scouring or plucking, sometimes with subsequent frost churning or weathering. Matrices of rounded boulders apparently result from heavy rinsing action along streams or lake shores.

(3) **Outwash.**—Sands or gravels that have been stratified and deposited by moving water. Stones, if any, are without silt caps.

(4) **Wet compact till.**—The compact tills in New Hampshire generally are considered to be of geologic origin—basal till compacted by the glacier. The wet compact tills exhibit a watertight layer at the base of the B horizon with mottling extending upward at least partly into the B horizon. Moving water often is present.

(5) **Dry compact till.**—The dry compact tills exhibit an abrupt change from friable to firm at the

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[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U. S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

base of the B horizon. The substrate varies from crisp to extremely hard, and usually is platy in structure. Imbedded stones are difficult to turn or remove. No mottling in the B horizon or moving water are present, possibly because of the porosity of the compact layer or the location of the habitat away from drainage ways.

(6) **Silty sediments.**—Sediments in this paper are defined as very uniform (poorly graded) materials deposited in slack water. The silty sediments are plastic and massive in structure; up to 80 percent by weight consists of silt or finer materials. Sometimes, stones or particles of weathered granite are incorporated into the sediments. Drainage sometimes is impeded.

(7) **Sandy sediments.**—These are poorly-graded materials that are loose and single-grained in structure. These materials resemble fine, well-sorted outwash except that silt caps are present.

(8) **Washed fine till.**—Till is the general name for unsorted glacial drift that has been dumped in place. However, some tills are rinsed or water-worked, probably because they were deposited as the glacier melted. These tills are loosely deposited, usually contain lenses or small blocks of stratified material, and have few surface rocks. The washed fine tills exhibit prominent silt caps. This substrate often occurs in areas containing sediments, which indicates that slack water played some part in their deposition.

(9) **Coarse till.**—These tills apparently were heavily rinsed as they were deposited, removing much of the fine material. The substrate is a loose sand/gravel or loamy sand/gravel. These tills resemble gravelly outwash, except that they have a broader gradation of particle sizes (including stones) and some evidence of silt caps.

(10) **Fine till.**—This is typical till deposited without any evidence of water working. All particle sizes are present; many surface rocks and irregular topography are characteristic. Textures are sandy loam or finer, sometimes with a noticeable silty feeling.

(11) **Enriched.**—These areas usually occur as coves or benches within areas of tills or occasionally compact tills. The distinguishing feature is organic matter or organic-coated fine material incorporated into the mineral horizons. Horizonation is poor. Drainage may be good to moderate or poor. Apparently, these areas are enriched by leaf litter and fine materials continually moving in from surrounding areas.

Table 1.—Numbers of plots, approximate range in plot elevations, and numbers of site-index trees by habitat

Habitat	No. of plots	Approximate range in elevation	No. of site-index trees
		m	
Poorly drained	6	366-427	6
Rock	21	244-671	17
Outwash	11	305-518	13
Wet compact till	22	274-549	13
Dry compact till	18	244-610	16
Silty sediments	12	274-610	11
Sandy sediments	11	244-488	10
Washed fine till	10	274-488	6
Coarse till	18	305-549	12
Fine till	6	335-640	6
Enriched	16	335-610	12
All	151	244-671	122

Elevations, numbers of plots, and numbers of site index trees by habitat are given in Table 1. Note that most habitats were found over a broad range in elevation. All plots were taken below the 760 m elevational mark commonly regarded as the transition point between the hardwood and boreal forest, although some of the rock habitats were found near this limit.

RESULTS

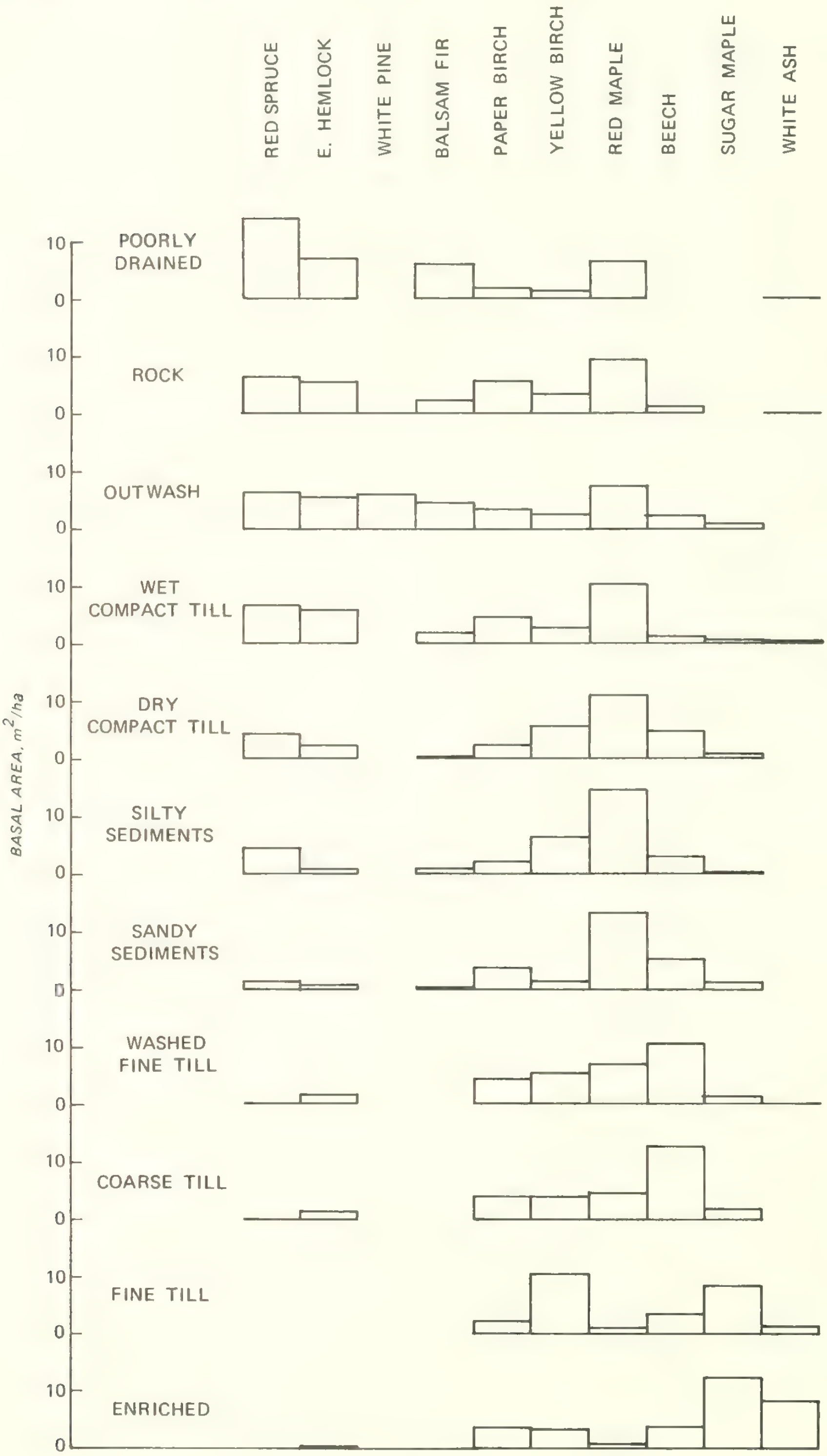
Species Composition

Average species composition of these successional stands in terms of m^2 of basal area per ha differs considerably among the 11 habitats (Fig. 1). To aid in visual comprehension, the habitats in Figure 1 are ordered approximately according to a decreasing component of red spruce and hemlock, with slight deviations to ensure that field-associated types of soil materials (e.g. compact tills or sediments) are adjacent to one another. The ordering of habitats clearly does not represent a simple gradient in moisture or soil texture.

Softwood species, especially red spruce and eastern hemlock, are abundant on habitats characterized by poor drainage, rock, outwash, and wet compact till. On these habitats, red maple is the most abundant hardwood, followed by the birches (yellow and paper). White pine is abundant only on outwash. Oak (*Quercus rubra* L.) sometimes was found on shallow bedrock or outwash.

Softwoods are present, though not abundant, on the dry compact till, on silty sediments, and (to a lesser extent) on sandy sediments. Red maple is

Figure 1.—Basal area in m²/ha by habitat for red spruce (*Picea rubens*), eastern hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), balsam fir (*Abies balsamea*), paper birch (*Betula papyrifera*), yellow birch (*Betula alleghaniensis*), red maple (*Acer rubrum*), American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and white ash (*Fraxinus americana*). Other hardwood and softwood species were omitted from the analysis.



the most abundant hardwood; the birches and beech are common associates.

Washed fine till and coarse till contain a preponderance of beech. Red maple and the birches are common associates. Softwoods are in the minority. Some of the largest concentrations of beech in the White Mountains seem to occur on coarse till that is not far removed from gravelly outwash.

Fine till is dominated by sugar maple, birch (especially yellow birch), and beech. This is the first habitat in Figure 1 in which sugar maple is at all abundant. Softwoods are completely absent.

On enriched sites, sugar maple and white ash are most abundant, although beech and the birches also are present. Softwoods are nearly absent. Although present on other sites, white ash is abundant only on the enriched sites.

Frequency of occurrence (percentage of plots containing a species) generally paralleled basal areas by species. If we concentrate upon those species that occur on at least 50 percent of the plots, we can better visualize the forest types or communities that characterize each habitat (Fig. 2). Successional stands on habitats characterized by poor drainage, rock, outwash, or wet compact till are dominated by softwoods, red maple, and birch. Areas of dry compact till, silty sediments, and sandy sediments abound in red maple, beech, and birch. Washed fine till and coarse till support heavy stands of beech with birch and some red maple. Fine till supports typical northern hardwoods—sugar maple, yellow birch, and beech. Enriched sites are similar to the fine tills, but support more sugar maple and ash.

Figure 2 also shows the two predominant tolerant species found on some habitats in old, uneven-aged stands. It is based primarily on an earlier study in the same part of the White Mountains (Leak 1976). Red spruce and eastern hemlock were the predominant tolerants found in old stands on poorly drained habitats down through dry, compact tills and silty sediments. Softwoods are not now abundant in successional stands on the dry compact tills and the silty sediments. However, iron cementation in the B horizon was found on 50 to 60 percent of the plots in these two habitats—an indication that softwoods recently were abundant (Buol et al. 1973). And 55 to 65 percent of the plots in these two habitats contained softwood regeneration judged to be at least as abundant as hardwood regeneration. Old stands of tolerant species on coarse till were dominated by beech, while sugar maple and beech were most common in old stands on fine till and enriched habitats.

Without heavy disturbance due to cutting, windthrow, disease, etc., the species composition of successional stands graphically shown in Figures 1 and 2 should gradually press toward the tolerant species numerically indicated in Figure 2. However, sediment cores from the White Mountains (Likens and Davis 1975) clearly show that major changes in tolerant species—from softwoods toward hardwoods—have taken place over the post-glacial period. So, we might expect that changes in the primary tolerant species will occur over future geologic time in response to climatic change as well as the continuing processes of soil formation; probably, such changes have occurred and will occur at different rates on different habitats.

Influence of Elevation and Disturbance

Although the discussion so far has dealt with habitat classifications, it is important to recognize that continuous environmental gradients may operate within habitat types. The data taken in this study could not be used for a thorough and precise analysis of elevational gradients. However, a comparison of basal areas by species above and below 457 m (1,500 feet) elevation within certain habitats indicates that red spruce is more abundant at higher elevations while hemlock is less abundant (Table 2). A similar pattern was detected in the previous work on habitats of old stands (Leak 1976). Certain hardwoods, such as beech and white ash, tended to decline somewhat incon-

Table 2.—Comparison of basal areas (m^2/ha) of red spruce and eastern hemlock above and below 457 m (1,500 feet) elevation for several habitats

Habitat	Elevation	Red spruce	Eastern hemlock
Rock	244-427	6.4	7.7
	548-671	6.0	1.3
Wet compact till	274-427	4.9	7.1
	488-549	13.2	2.4
Dry compact till	244-396	.8	2.6
	457-610	7.2	1.8
Silty sediments	274-305	—	.8
	457-610	7.1	1.1
Coarse till	305-442	—	1.4
	457-549	.6	.6

Figure 2.—Percentage of plots containing each species in successional stands, including only those species that occur on 50 percent or more of the plots. Numbers 1 and 2 indicate the most common and second most common of the tolerant species found on several habitats in a previous study of old, undisturbed stands (Leak 1976).

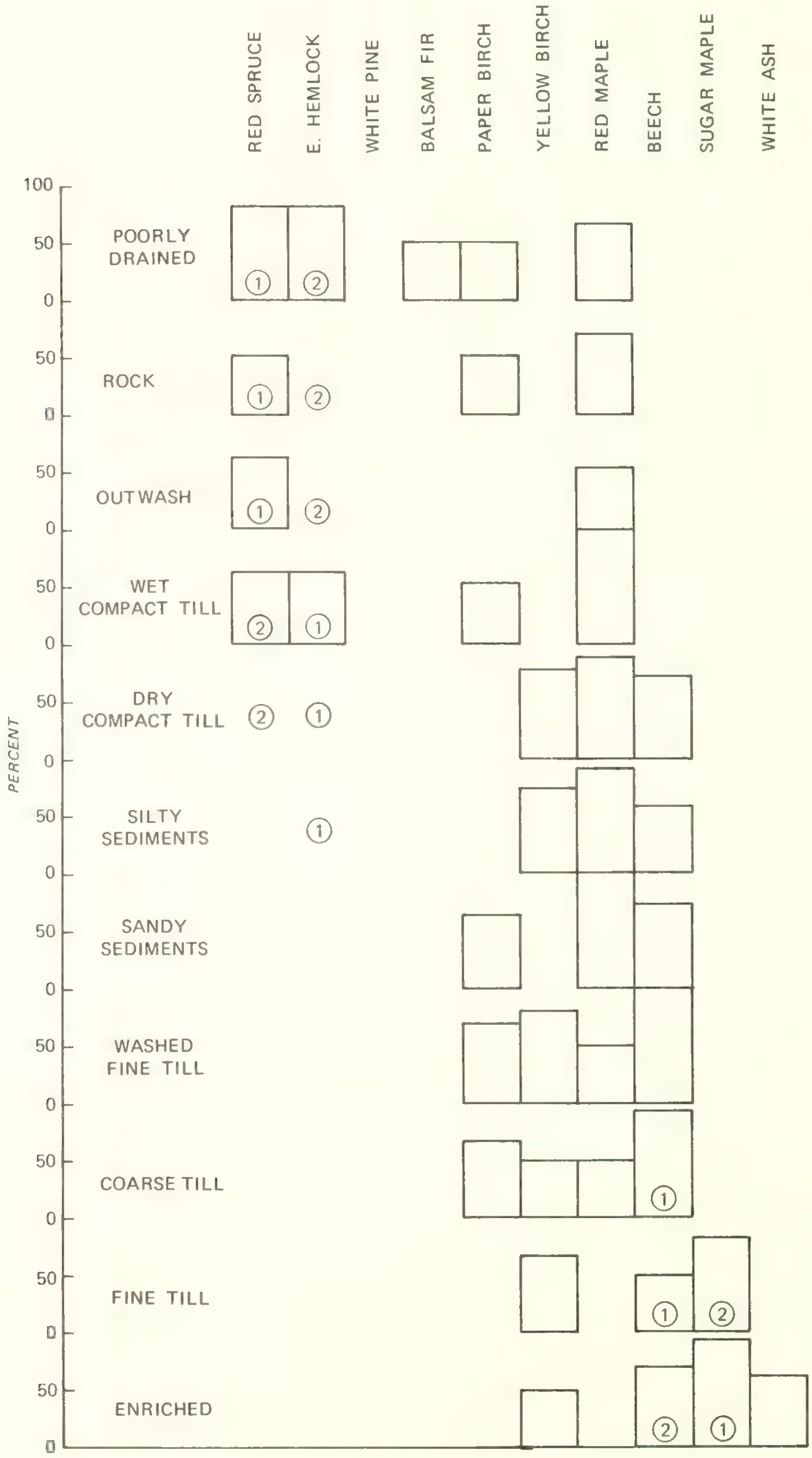


Table 3.—Comparison of basal areas (m^2/ha) by species on undisturbed (18 plots) and disturbed (pastured, 3 plots) coarse till

Disturbance	Red spruce	Eastern hemlock	White pine	Balsam fir	Paper birch	Yellow birch	Red maple	Beech	Sugar maple	White ash
Undisturbed	0.2	1.2	—	—	4.0	4.0	4.5	12.7	1.8	—
Disturbed	1.0	7.0	—	—	5.0	—	2.0	8.0	2.0	—

sistently with higher elevation while the birches seem less consistently responsive to increased elevation. Apparently, habitat classification does not eliminate the need for recognizing elevational gradients, but simply provides an added dimension to such work.

Although the study was restricted for the most part to nonfarm sites, three plots were taken on coarse till that had been heavily pastured 60 to 100 years before. These sites had a thin organic layer, a missing or poorly developed A_2 horizon, and poor horizonation elsewhere in the solum; a search nearby revealed old cellar holes and stone walls. In comparison with the undisturbed sites, the pastured areas had more softwoods; hemlock was the second most abundant species (Table 3). Observations elsewhere in the White Mountains indicate that white pine may also be abundant in old pastures on soil materials that usually support hardwoods. Note also that paper birch is the predominant birch on the pastured sites.

Productivity

Productivity was evaluated in terms of site index, the total height of dominant trees at age 50 (either total age or age at breast height depending upon the available site index curves). Site index is a common measure of productivity for timber management purposes.

The relationships between habitat and productivity varied by species (Table 4). The highest site indexes of white ash, sugar maple, paper birch, and possibly yellow birch are found on the fine tills and enriched areas. Site index of these species generally is lower on habitats that support higher proportions of softwoods, the poorly drained and rock habitats for example. Sugar maple apparently has a much lower site index on habitats other than the fine tills and enriched areas. From results with these four species, it seems that habitats dominated by hardwoods generally exhibit a higher site index than those with a softwood influence. However, red spruce and red maple—a common associate of softwoods— showed limited or inconsistent differences in site index among habitats.

DISCUSSION

Species composition and productivity (site index) vary appreciably among 11 habitats defined for areas of granitic drift in the White Mountains of New Hampshire. Successional stands of beech—sugar maple—birch (especially yellow birch) characterize the fine tills and the enriched sites (where white ash also is common). Washed fine till and coarse till support beech and birch with some red maple. Red maple is a predominant species on sandy sediments, silty sediments, and dry compact till, where it occurs with birch and beech; some softwood influence usually is evident on these sites as well. Softwoods (especially red spruce and eastern hemlock), red maple, and birch characterize the habitats representing poor drainage, rock substrates, outwash and wet compact till. Site index generally averages highest on the strong hardwood sites, and lowest on the strong softwood sites. However, species such as red maple maintain fairly high site index even on the strong softwood sites.

Habitat classifications such as this should prove useful in forest land classification, especially when used in conjunction with (1) aerial mapping techniques based on land form and (2) known environmental gradients such as elevation. Since the habitats described in this paper are defined by the physical nature of soil materials, the relationships may differ in areas of different mineralogy, such as drift derived from slaty or crystalline schists (Whittaker 1953).

With the exception of the enriched sites and perhaps the dry compact tills, the habitats described in this paper can be found in units of 20 to 40 hectares or more. However, they may occur in smaller units; and some tracts can only be described as a complex of two or more habitats. The influence of habitat upon vegetation appears to be stronger where the acreage in any given habitat is

Table 4.—Mean site index in feet (and meters) plus and minus one standard error of the mean. Base age 50 years. Based on 122 samples

Habitat	Red spruce[a]	White pine[a]	Balsam fir[a]	Paper birch[b]	Yellow birch[b]	Red maple[a]	Beech[a]	Sugar maple[b]	White ash[b]
Poorly drained	44 ± 4(13.4)	—	—	—	48 (14.6)	—	—	—	48(14.6)
Rock	44 (13.4)	60 (18.3)	—	56 ± (17.1)	48 ± 4(14.6)	60 ± 0(18.3)	—	—	—
Outwash	40 ± 3(12.2)	56 ± 3(17.1)	54 ± 6(16.5)	—	60 ± 6(18.3)	63 ± 3(19.2)	—	—	—
Wet compact till	38 ± 2(11.6)	—	—	54 ± 3(16.5)	57(17.4)	52 ± 6(15.8)	—	—	70 ± 2(21.3)
Dry compact till	44 ± 4(13.4)	—	—	70 (21.3)	56 ± 3(17.1)	60 ± 2(18.3)	57(17.4)	—	—
Silty sediments	51 ± 2(15.5)	—	—	62 ± 0(18.9)	62 ± 7(18.9)	64 ± 4(19.5)	—	—	—
Sandy sediments	—	—	—	68 ± 2(20.7)	61 (18.6)	52 ± 2(15.8)	—	60(18.3)	—
Washed fine till	—	—	—	66 ± 5[c](20.1)	80[c](24.4)	—	57(17.4)	—	—
Coarse till	—	—	—	66 ± 2(20. 1)	55 ± 4(16.8)	—	65 ± 4(19.8)	50 ± 8(15.2)	—
Fine till	—	—	—	77 (23.5)	68 (20.7)	—		68 ± 6(20.7)	76(23.2)
Enriched	—	—	—	74 ± 6(22.6)	63 (19.2)	—	—	72 ± 4(21.9)	81 ± 3(24.7)

[a] Total age 50 years

[b] Breast-high age 50 years.

[c] Consists of or contains a measurement on a young stand (35 years), which may overestimate site index.

greater. As with any classification scheme, a certain amount of comparative field work is necessary before habitats can be readily identified.

Additional research is needed on the nature of the transition—in soil materials and vegetation—from one habitat to another. Examples of very sharp transitions between till and rock substrates have been noted (Leak 1976), and deposits of outwash and wet compact till often are well defined in terms of vegetational change and habitat boundaries. The chief problems to date have been in making clear boundary distinctions between outwash and coarse till, and between sediments and washed fine till. With additional information on transition patterns, the distinction between gradient analysis and classification analysis may gradually disappear. Landscapes may eventually be described in terms of many gradients varying from gradual to abrupt.

The reasons why species and site index differ among habitats have not yet been determined. Certainly, nutrition is involved as well as water relations in certain cases (e.g. poorly drained habitats). However, chemical analyses of some of the soils in the White Mountains (Hoyle 1973) have not provided any clear nutritional basis for habitat differentiation.

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Coniferous Understory Influences Sugar Maple (Acer Saccharum Marsh.) Sap Production

by Russell S. Walters

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ABSTRACT

Sap and maple syrup equivalent production increased after a coniferous understory was removed from a sugarbush in northwestern Vermont. These increases, which became apparent the sixth year after treatment, were 14 and 17 percent for sap and syrup respectively, relative to the yields from an adjacent open sugarbush. The open sugarbush yields were used as the control in the analysis, to indicate the influence of weather conditions in each sapflow season. Understory removal also stimulated growth of the overstory maple trees.

INTRODUCTION

CONIFERS IN a sugarbush are thought to compete with the sugar maple trees for soil moisture and nutrients, thus reducing sapflow and lowering sap sugar production. It is an accepted practice to remove these conifers, but it was not known whether this practice was really beneficial or merely convenient.

We found that it is beneficial. A closed sugarbush with a coniferous understory consistently produced less syrup equivalent per taphole than an adjacent bush of similar trees growing in an open, parklike stand. After the understory was removed, the difference disappeared and the two sugarbushes produced almost equal amounts per taphole. This information is of practical value for sugarbush improvement. It also indicates that the sapflow mechanism can be manipulated to increase sap and sugar production through modification of the sugarbush timber stand characteristics and thus, the microclimate characteristics.

STUDY METHODS

This study was installed on two adjacent portions of the Mitchell sugarbush in the town of Essex in Chittenden County, Vermont. Each area covered about 0.5 hectare. One part, in addition to the overstory of sugar maple *(Acer saccharum* Marsh.), was heavily populated with a mixture of hemlock *(Tsuga canadensis* (L.) Carr), and white pine *(Pinus strobus* (L.)) in the understory. A few conifers also reached into the overstory. We call this the "closed" sugarbush before the understory was removed, and the "cut" sugarbush thereafter. The other area had a very open, parklike sugar maple stand with no conifers; we call it the "open" sugarbush (Fig. 1). The cut and the open sugarbushes are actually portions of the same sugarbush; the understory developed in part of the stand that was protected from cattle grazing. After the coniferous understory was removed from the cut portion, the entire sugarbush appeared very uniform in sugar maple size, spacing, stand density, and site quality. The entire area has

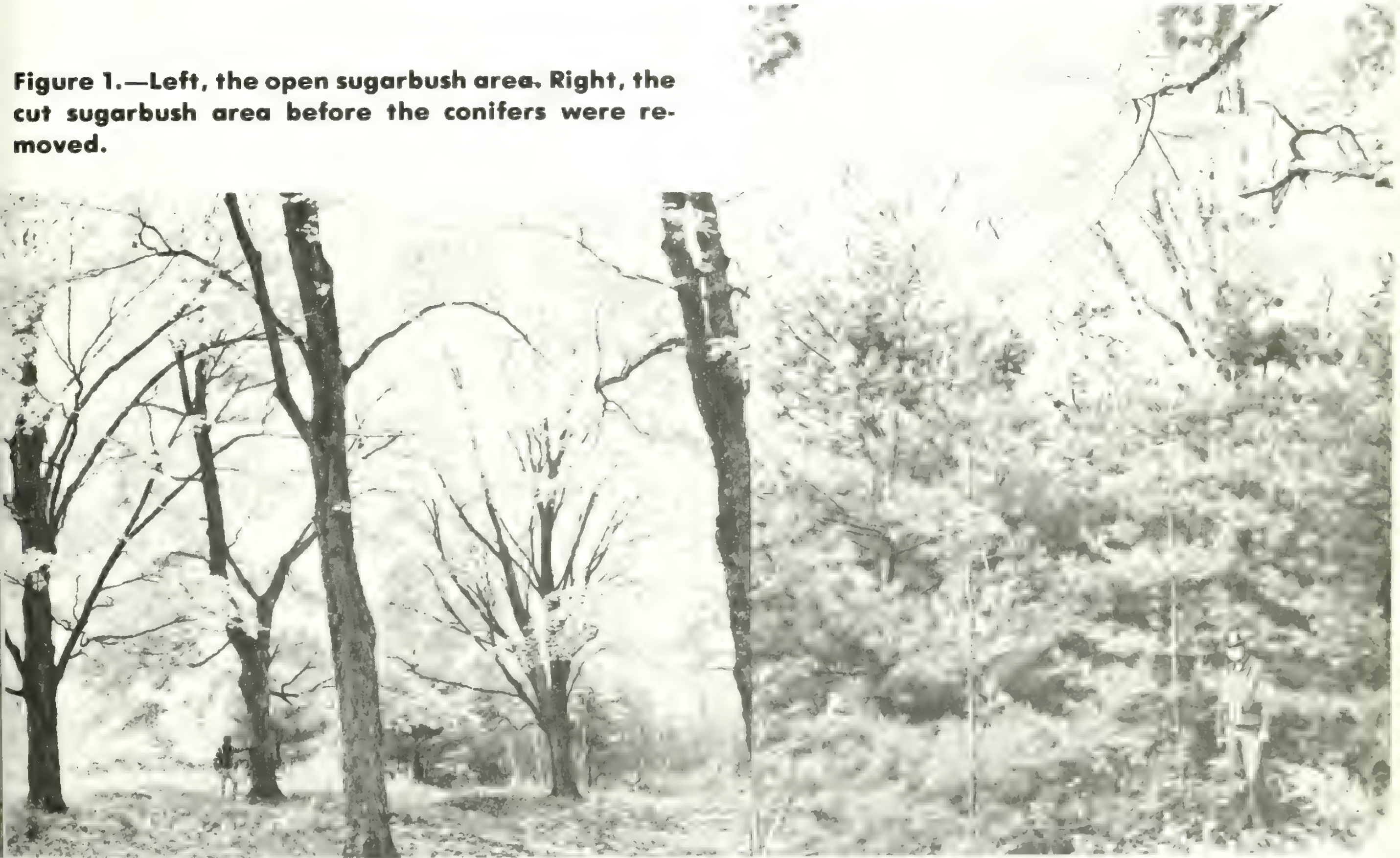


Figure 1.—Left, the open sugarbush area. Right, the cut sugarbush area before the conifers were removed.

been protected from grazing since the establishment of this study.

The Mitchell sugarbush is at 250 meters elevation in the foothills of the Green Mountains east of the Champlain Valley. The soil is Lyman very rocky loam, and is shallow, with numerous outcrops and ledges and excessively drained. Lyman soils are less than 50 cm to bedrock; they are usually saturated during early spring but dry out quickly and are low in available moisture capacity. They have low natural fertility and are rated only fair for timber production (Allen 1974). The terrain is nearly level, but undulating, with numerous hummocks.

Before the conifers were removed, the maple trees in each portion of the sugarbush were tapped and sap was collected over a 3-year calibration period to determine the average annual sap-volume yield and sap-sugar percentage for each tree. This was done during the 1965, 1966, and 1967 sapflow seasons.

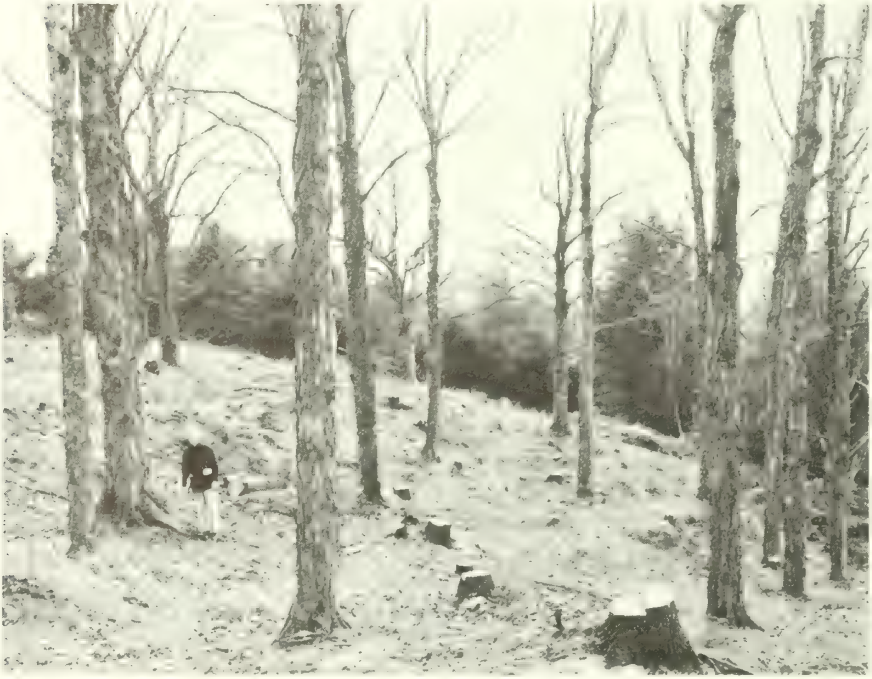
We then selected 28 of the highest-yielding trees in the open sugarbush and 28 of the highest yielding trees in the closed sugarbush. Grouping the trees this way on the basis of previous sap-yield data makes it possible to detect smaller treatment differences (Blum and Gibbs 1968). The selected trees ranged in dbh from 30 to 84 cm; the average diameter in the open sugarbush was 53 cm, in the closed area, 46 cm.

During October 1967, all the white pine and hemlock stems 2.5 cm or more in diameter, a total of 656 stems, were cut and removed from the closed sugarbush (Fig. 2). This area was 0.5 hectare. The basal area of cut material was equivalent to 14.9 m^2 per hectare. Most of the conifer stems were in the overtopped or intermediate crown class. The diameters and numbers of pines and hemlocks were:

Diameter class *cm*	*White Pine*	*Hemlock*
2.5 — 12.6	117	421
12.7 — 17.7	16	34
17.8 — 22.7	2	20
22.8 — 27.8		17
27.9 — 32.9	2	15
33.0+		12
Total	137	519

Each year, standard-size tapholes (1.1 cm in

Figure 2.—A portion of a cut sugarbush area after the conifers were removed.



diameter) were drilled into the southern side of each sample tree to a wood depth of 7.5 cm at approximately 1.5 m above ground. The same tapping procedures were followed every year. Extreme care was exercised to insure that all tapholes were as nearly uniform in dimensions as possible.

A plastic sap spout with a piece of plastic tubing attached was inserted into each taphole. The sap from individual tapholes was collected in separate plastic containers and measured to the nearest 0.5 liter (Fig. 3) to determine the total yield for the season for each tree in the study. Sap was measured during the calibration period and also, after the conifers were removed during the "sugaring seasons" of 1968 through 1976, except for the 1971 and 1972 sapflow seasons, when sap was collected from only 9 trees in the open bush and 11 trees in the cut bush.

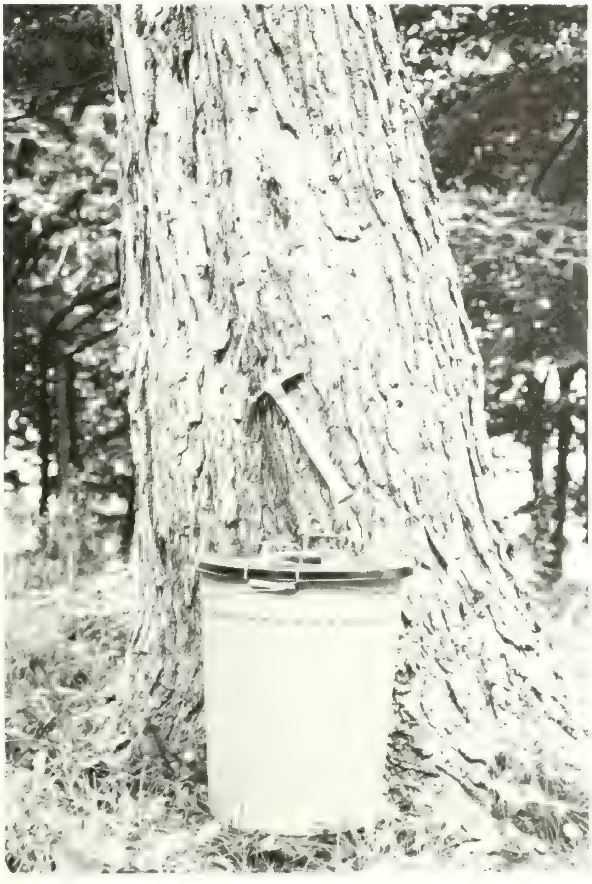


Figure 3.—Maple sap from each taphole was collected separately in covered plastic containers. The total sap volume per season for each taphole was determined to the nearest 0.5 liter.

Sap-sugar percentages were computed as the average of three or more readings per season made with a sap-sugar refractometer, which measures sugar concentrations to the nearest 0.1 percent.

Annual syrup-equivalent yield was computed for each tree from the sap-volume and sap-sugar data. This is the amount of syrup that could have been produced from the sap collected, and is a useful measure of the performance of the tree.

The data were analyzed by multivariant analysis of variance, carried out by making simultaneous comparisons among the average annual yields during the posttreatment period, and the corresponding average yields during the calibration period. The yield data from the open sugarbush were used as controls to indicate the magnitude of influence exerted on sapflow by the weather conditions in each season.

Growth response to the removal of the understory was assessed by extracting increment cores from a sample of 16 trees. Radial growth for the 9-year period before the treatment and for the 9-year period after treatment was measured in each portion of the sugarbush. These data were compared by a t-test for paired replicates.

RESULTS

During the 3 sap seasons of the calibration period and the 3 following years, an average of 14 percent less sap was collected from the trees in the cut sugarbush than from those in the open sugarbush (Table 1), but only in 1965 was the difference statistically significant. In 1973, the sixth sap season after treatment, and each year thereafter, the annual average sap volume per taphole from the cut sugarbush was slightly greater than that from the open sugarbush.

Sap sweetness, as indicated by the percentage of sugar in the sap, was significantly greater in the closed sugarbush than in the open sugarbush for 2 of the 3 years before the conifers were removed (Table 1). After removal of the conifers, the average sugar contents were similar. Only in one posttreatment year (1969), was the difference in sugar content great enough to be significant, and that difference was only 0.3 percent.

The understory removal did stimulate radial growth. In the trees within the cut sugarbush, the radial growth averaged 16 mm during the 9 years after treatment; during the preceding 9 years, it averaged 11 mm, an increase of 5 mm ($p \leq .01$). The resultant increase in the width of annual

Table 1.—Average maple sap volume, sap-sugar content, and syrup equivalent from "open" and "cut" portions of a northwestern Vermont sugarbush before and after removal of a coniferous understory

Year	n		Sap volume		Sugar concentration		Syrup equivalent	
	Open	Cut	Open	Cut	Open	Cut	Open	Cut
			—Liters—		*—Percent—*		*—Liters—*	
Pretreatment								
1965	28	28	79.5	54.1**	2.7	3.0**	2.58	1.88**
1966	28	28	89.4	76.3	2.9	3.3**	3.15	2.96
1967	28	28	69.4	67.5	3.0	2.2**	2.41	1.80*
Posttreatment								
1968	28	28	46.3	41.8	2.6	2.5	1.42	1.20
1969	28	28	75.6	73.9	2.6	2.3*	2.25	2.02
1970	28	28	84.5	71.0	2.5	2.4	2.43	1.93*
1971	9	11	102.2	87.4	2.5	2.5	2.93	2.71
1972	9	11	95.0	87.4	2.8	2.9	3.20	2.92
1973	27	28	54.7	58.1	2.4	2.4	1.57	1.65
1974	28	27	45.1	46.8	3.2	3.2	1.76	1.74
1975	28	28	64.3	69.5	2.5	2.6	1.91	2.07
1976	26	27	55.6	58.2	2.3	2.0	1.48	1.32

* Difference between open and cut sugarbushes significant at 5-percent level.
** Difference between open and cut sugarbushes significant at 1-percent level.

growth rings became visible in 50 percent of the sampled trees the second year after release, and by the third year, it was apparent in all the sampled trees. In the open sugarbush, the average radial growth was the same (13 mm) for the 9 years before and the 9 years after the time of the understory removal.

DISCUSSION

I believe that removing the coniferous understory made more moisture, nutrients, and growing space available, which resulted in faster growing, more productive trees with large crowns. The response in growth rate to the release treatment shows that physiological activity increased. The influence of fast growth, increased tree vigor, and large crown area on sap and total sugar production is well documented (Blum 1973; Moore et al. 1951; Jones et al. 1903).

Sap yield and syrup equivalent yield generally followed the same trends. In 9 of the 11 sap seasons observed, the sugarbush with the greatest sap yield per taphole also gave the most syrup equivalent per taphole (Table 1). The 1974 and 1976 sap seasons were exceptions; differences in these years were minimal. On the other hand, the percentage of sugar was relatively unimportant in computing syrup equivalent volumes. The sugarbush with the higher sugar concentration was usually the one that also produced the higher sap volume. Blum (1973) also observed that sap volume was very important in explaining total sugar yield, and sugar concentration relatively unimportant.

I observed that in the closed sugarbush there was less variation in daily air temperatures from January to April than the open sugarbush, and that the temperature rose more gradually during the day.

The maple sapflow mechanism is known to be extraordinarily sensitive to temperature changes; a 2- or 3-degree rise is often sufficient to initiate a good flow. The twigs are regarded as being the most sensitive to air temperature changes, but the best flows usually occur when the entire tree is warmed rapidly (Marvin 1969).

I believe that trees warm faster when there is no understory. If so, sapflow would begin earlier in the day, during the usual time of peak flow. On some days, the closed sugarbush may not warm enough to produce a flow, or only enough to trigger a "weeping" flow, while the open bush produces a good flow. Jones et al. (1903) noted that on good flow days most of the sap and sugar was generally yielded before noon (63 percent of the total). The flow then diminished gradually until about 3 p.m., then declined rapidly.

The differences in sugar concentration noted during the calibration period are interesting and confusing. In 1965 and 1966, the average sugar concentration was significantly ($p \leq .01$) greater in the closed sugarbush. Then the relationship reversed, and the open sugarbush produced a significantly higher sugar concentration. The year after removal of the understory, and at each observation since, the differences in sugar concentration between the two areas were much smaller. In only 1 of the 9 years after treatment was the difference statistically significant.

I believe that this effect is due to the influence of the coniferous understory on daily air temperature variation. Changes in sap-sugar content can be induced by temperature change. The enzymes that convert starches to sucrose are more active at lower temperatures (Kramer and Koslowski 1960). The peak rate of conversion occurs at about 4° C. As the temperatures rise above 5° C, the process reverses, and starch is resynthesized (Höll 1975). Marvin et al. (1971) also found in the laboratory that temperatures of 4° C induced the conversion of starch to sucrose in the cells of maple tissue. When the temperature pattern in the closed sugarbush differs from that in the open bush, starch conversion would proceed at different rates, and thus the sugar percentages would differ.

The sapflow mechanism is thought to function at the cellular level, and differences in sapflow and sugar content may be explained by different numbers of certain cell types (Marvin 1958). Reserve carbohydrates are stored mainly in parenchyma, and in sugar maple the bulk of this storage is in the ray cells. Sauter et al. (1973) have shown that release of sucrose in sugar maple depends on respiratory activity within specialized cells of ray and axial parenchyma called "contact cells". These connect the axial and radial parenchymal systems with the vessels,and have numerous large elliptical pits facing the vessels. It is conceivable that the number of contact cells increases as the ray cell population increases. This, in turn, could increase both sapflow and sugar release, producing larger sapflows and increased sugar production, although not necessarily higher sugar concentrations. Xylem ray abundance can be silviculturally manipulated: it increases when the tree's growth rate is increased (Gregory 1977).

This hypothesis explains the increased sugar production observed in our study, because we also observed the increase in growth rate. It also helps to explain the time lag before the increased production became evident. If a change in cambial activity caused a change in the number of xylem ray cells, and this, in turn, changed the trees' sapflow pattern, several years would be required before sufficient wood could be produced to establish these new sapflow characteristics.

The increased yield from the treated area did not become evident until the sixth season after treatment (1973), but it is possible that it could have been detected in 1971 or 1972 (Table 1). Our data for these 2 years suggest the possibility, but are too limited to fully support such a conclusion.

CONCLUSION

We found that the coniferous understory in this sugarbush did inhibit syrup equivalent production and tree growth. Removing it increased sugar production after a lag of several years, as well as improving accessibility and working conditions in the sugarbush. We recommend removing any coniferous understory from sugarbushes.

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Effects of Fertilization on Shoot Growth of Defoliated and Undefoliated Red Oak Seedlings

by Johnson Parker

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1978

FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
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Abstract

Fertilization of red oak (*Quercus rubra* L.) seedlings increased their terminal shoot growth. Dry, liquid, and liquid + dry fertilizer was applied to groups of undefoliated, once-defoliated, and twice-defoliated seedlings. Terminal shoot growth was measured after the first and second growing season and compared to that of a similar group of unfertilized seedlings. On the average, defoliated seedlings treated with dry or liquid + dry fertilizer grew more than unfertilized, undefoliated seedlings. The foliage color of twice-defoliated seedlings was not influenced by fertilization, but a difference in leaf color between unfertilized and some of the fertilized seedlings was observed. The liquid + dry fertilizer stimulated growth more than the other fertilization treatments.

THE PROBLEM

Usually nothing is done to enhance vigor and growth of forest trees that have been severely defoliated by insects. However, dry or liquid fertilizer could be applied to the soil in the hope that it would stimulate vigor in coming years. The effects of fertilizer on the recovery of defoliated trees are unknown, but a previous study (Parker and Patton 1975) indicated that fertilization of defoliated seedlings had no effect on recovery other than to produce darker green leaves and decrease carbohydrate levels. In that study, growth was not specifically measured, and only a liquid fertilizer was used.

The present study was designed to test the effects on terminal shoot growth of red oak (*Quercus rubra* L.) seedlings of 10/10/10 fertilizer, a nutrient solution, and the two together in factorial combination with various defoliation treatments.

METHODS AND MATERIALS

Ninety-six seedlings of red oak that were grown for 2 years from seed in 24-cm diameter, 24-cm high pots were divided into 12 groups of eight seedlings, with one seedling per pot. The planting medium was prepared by mixing equal amounts of sand and loam soil of low fertility obtained from a forest site. The sand-loam mixture had a pH of 5, and N, P, and K concentrations that were moderately deficient according to a standard soil test. The experiment was conducted in a greenhouse that was maintained at a temperature of about 28 C. Seedlings were moved outside during winter.

Of the 96 seedlings, 32 were undefoliated; 32 received one defoliation treatment on 30 April 1976; and 32 received defoliation treatments on 30 April and 28 May 1976.

Eight seedlings in each group received no fertilizer, and eight in each group received each of the three fertilizer treatments.

The 10/10/10 fertilizer contained 1,500 mg N, 650 mg P, and 1,250 mg K per 15 g. This quantity was based on the amount successfully used for trees in the field (Neely et al. 1970). The nutrient solution (Hoagland 1920) contained 420 mg N, 62 mg P, and 465 mg K per liter, plus additional amounts of essential elements.

The dry fertilization treatments were made in one application on 30 April 1976 by adding 15 g of the 10/10/10 to four 10-cm deep holes in each pot. The nutrient solution was applied on 30 April and again on 28 May 1976 at the rate of 1 liter per pot. Before the nutrient solution was added, the pots were allowed to dry out for 2 days to assure maximum uptake of the solution. Only a minor portion of liquid passed through the pots.

In the fall of 1976, the terminal growth of the seedlings' leaders and laterals was measured. This growth included three flushes in the twice-defoliated seedlings, two in the once-defoliated, and one or two in the undefoliated. Lengths of all new shoots were measured again in late May 1977 following the spring flush for that year.

RESULTS

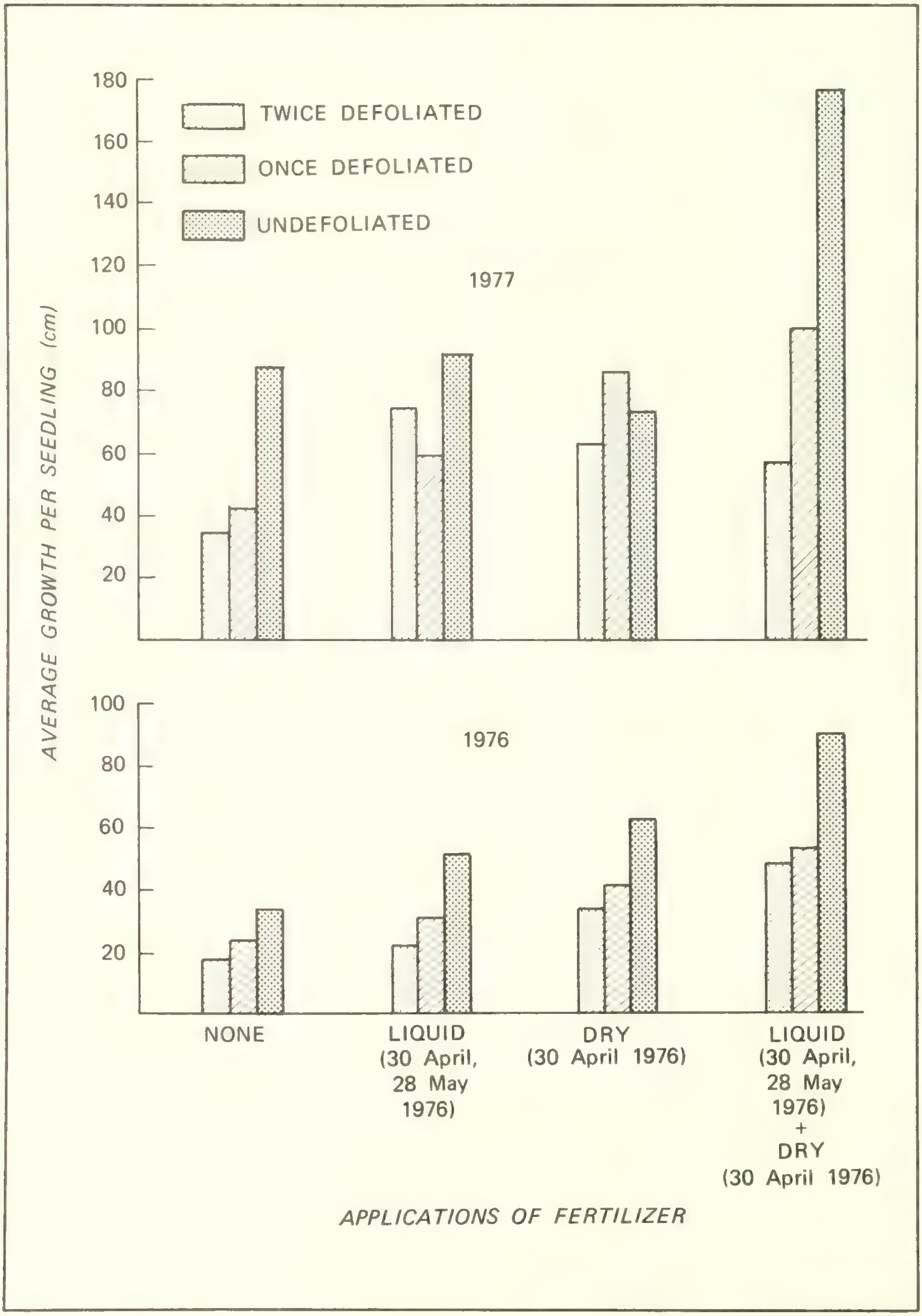
In the first growing season—1976—there were definite differences in growth among treatments (Fig. 1, bottom). An analysis of variance showed that differences were significant among fertilizer treatments and defoliations, but not among their interactions at the 5 percent probability level. In each treatment category and the control, growth was greatest in the undefoliated seedlings and least in those twice defoliated. With fertilizer added, growth increased in once- and twice-defoliated seedlings more than in the control seedlings. The addition of nutrient solution to defoliated seedlings improved growth; growth increased even more by the use of dry fertilizer alone, and was further improved by the application of liquid + dry fertilizer.

Of special interest is that once- or twice-defoliated seedlings grew faster than control seedlings when they were treated with dry or liquid + dry fertilizer. Although statistical comparisons of any two treatment combinations (represented by bars in Fig. 1, bottom) showed no significance at the 5 percent level, the addition of liquid + dry fertilizer increased growth about half again as much in twice-defoliated seedlings as in control seedlings.

During the winter of 1976-1977, mice girdled and killed many seedlings. The growth patterns of the surviving seedlings are shown in Figure 1, top. Growth by late May 1977 followed much the same pattern as in the previous season, although it was much more irregular. On the average, the once-defoliated, although not the twice-defoliated seedlings that were treated with liquid + dry fertilizer grew more than the control seedlings (Fig. 1, top).

We observed foliage color in late June 1976, when there seemed to be real differences among treatment of twice-defoliated seedlings. New

Figure 1.—Average seedling shoot growth for 1976 (bottom) and 1977 (top) by defoliation and fertilization treatments. Bars in the 1976 groups represent an average of eight seedlings; in 1977, the number of seedlings varies. Analysis of variance showed significant differences (5 percent level) among defoliations and among fertilizer treatments, but not among interactions. Statistical comparisons of any two individual treatment combinations (bars in figure) showed no significance at the 5 percent level.



leaves were lighter green than those of undefoliated or once-defoliated seedlings regardless of fertilizer treatment. New leaves of fertilized, undefoliated and once-defoliated seedlings tended to be darker green than those of unfertilized seedlings.

DISCUSSION

This experiment indicates that fertilizers can improve growth and vigor of defoliated seedlings over those of unfertilized, undefoliated seedlings. The greater effectiveness of the dry fertilizer was probably because it contained more of N, P, and K than the nutrient solution. The increased growth following each of the fertilizer treatments was probably the result of N and perhaps P in combination with N, judging by the results of tests by Phares (1971) and Auchmoody (1972).

Whether these results can be extrapolated to forests that contain large trees with extensive root systems and to soils with varying nutrient and moisture levels is questionable. Under those conditions, growth response to fertilization might be entirely different from the results observed here. Nevertheless, from my studies (unpublished) of forest soils in southern New England, it has been my impression that most of the soils were very low in N, P, and K, and that forest trees should respond well to fertilizers.

In this experiment, the effects of fertilization evidently persisted into the second year, although the results were more erratic. This irregularity is perhaps because fertilizers were being used up and the ill effects of defoliation were being overcome by storage of new photosynthates. It also reflects the reduction in the number of seedlings.

Mortality of shoots during the first and second seasons was very low. Two defoliations increased shoot mortality, but fertilizer treatments had no consistent effect on its increase or decrease. Shoot mortality was so irregular among treatments that few clear conclusions could be drawn. Therefore, results have not been presented.

The next logical step in this research would be to test some commercial fertilizers in forests and compare the growth of defoliated and undefoliated trees. Shigo (1973) however, warns that fertilizers—at least when used in excess—may increase forest trees' susceptibility to insect infestations and fungus disease. In general, however, fertilizers should enhance tree vigor and help prevent increase in susceptibility.

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SKYLINE HARVESTING IN APPALACHIA

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Abstract

The URUS, a small standing skyline system, was tested in the Appalachian Mountains of north-central West Virginia. Some problems encountered with this small, mobile system are discussed. From the results of this test and observation of skyline systems used in the western United States, the authors suggest some machine characteristics that would be desirable for use in the Appalachians.

The Authors

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IN THE Appalachian mountains, most timber is harvested by ground skidding systems. Wheeled skidders are the most widely used machines. A major criticism of skidder operations is the dense road network required to move the logs to landings. Often these road systems are poorly planned, do not protect other resources, and are esthetically unpleasant when viewed in the landscape.

For example, Kochenderfer (1977) measured bulldozed roads on nine skidder- and two jammer-logged jobs in north-central West Virginia. On skidder jobs, road spacing seldom exceeded 150 feet, with one mile of road required to log about 20 acres. On the jammer jobs, where a truck crane was used to yard and load logs, road spacing averaged about 250 feet; here, 1 mile of bulldozed road was needed to log about 31 acres. With a standing skyline cable system, we were able to log about 80 acres from 1 mile of road.

On the Fernow Experimental Forest near Parsons, West Virginia, we tested a standing skyline cable system[1] that might have application in the central Appalachian mountains. The Forest Engineering Project of the Northeastern Forest Experiment Station from Morgantown, West Virginia, cooperated in these tests.

The machine was a URUS,[2] a small mobile unit made in Austria with a skyline capacity of 1,100 feet of ⅞-inch cable (Fig. 1). The unit has a 28-foot tower and a carriage that automatically clamps onto the skyline when stopped. The corri-

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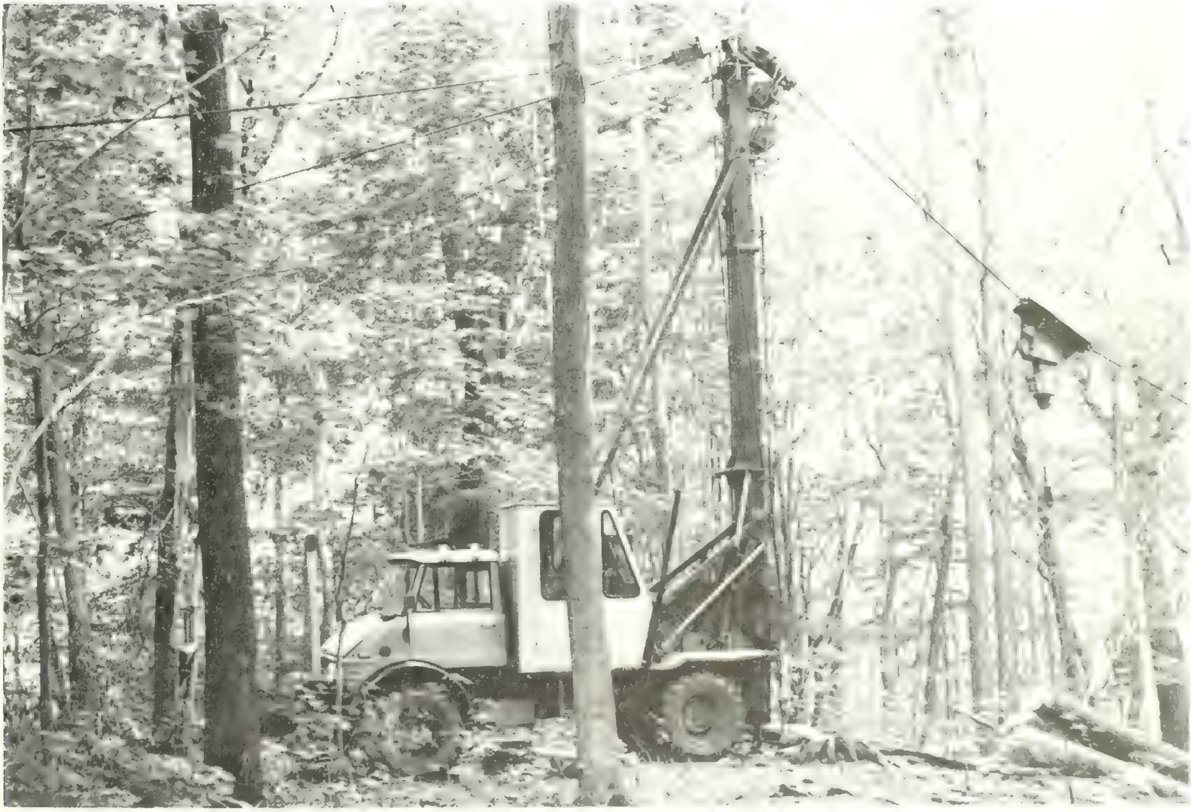
[1] For definitions of cable logging terms, refer to the glossary at the end of this paper.

[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Figure 1.—The URUS, the skyline system used in these tests.



dors ranged from 600 to 900 feet long and averaged 789 feet. Spacing between corridors averaged 150 feet. Since the URUS had previously been used almost exclusively in clearcutting, we confined our tests to partial cutting. Average lateral yarding distance under these conditions was 75 feet on either side of the skyline.

We also observed cable systems, including live and running skylines, currently used in the eastern and western United States. Although we recognize that skyline cable systems differ in mechanics and complexity (Studier and Binkley 1974), all can be used in clearcutting and in partial cutting.

Topography

Topography is extremely important in determining the utility of any skyline system because regardless of the system used, there must be adequate clearance between the ground and skyline. In mountain country, skylines operate best on concave slopes, with all logs yarded across the hollows. However, there is a great diversity of topography in the central Appalachians and frequently concave and convex slopes are mixed with small benches and frequent rock outcrops (Fig. 2). With skyline spans of 800 to 900 feet, the URUS needed at least one, and frequently two, intermediate supports to elevate the skyline so that the front ends of logs would pass over obstructions. Slope is important in gravity-feed systems, especially when small and relatively light carriages are used. The carriage must gain sufficient momentum to unspool and drag several hundred feet of mainline cable. In the West, slopes must be greater than 25 percent for these systems to operate efficiently. On lesser slopes and in downhill yarding, power must be used to pull out the carriage and pull slack for lateral yarding.

Unfavorable topography can be overcome to some extent by building roads in the most favorable locations possible. Other measures to counteract it are (1) shortening the skyline span, (2) elevating the skyline block or anchor, (3) increasing the height of the tower, and (4) using intermediate supports. For example, we used a 28-foot tower to log 39 corridors with the skyline block elevated to 30 feet and an average skyline length of 789 feet. Two supports were required on 15 of these corridors, 17 required 1 support, and 7 required no supports. The results of an analysis of the same ground profile data showed that with a 40-foot tower on the URUS, 11 corridors could have been logged without supports. By shortening the skyline to 500 feet and using a 28-foot tower, 55 percent or 21 of the corridors probably could have been logged without intermediate supports. By raising tower height to 40 feet and holding spans to 500 feet, we could have logged 85 percent or 33 of the corridors without supports. The slopes we logged averaged 46 percent and were relatively constant convex slopes with numerous rock outcrops up to 15 feet high. As previously pointed out, slopes like these are the least desirable for cable logging. We believe that many spans longer than 500 feet cannot be logged without intermediate supports in the central Appalachians because of topographic restrictions.

Cable logging should not necessarily be restricted to steep land. Many of the skyline systems that we observed had the capability of logging relatively gentle topography. The use of cable systems on gentle slopes (e.g. 30 percent) would eliminate about as many roads as on steep slopes (e.g. 50 percent) because road density is controlled by factors other than steepness. Logging methods, topography, and obstacles such as cliffs, streams, and property lines influence road density. In general the less steep areas in the eastern mountains are often the best timber growing sites. Skyline logging would require a lower road density and damage to the site from compaction would be minimized.

Much of the timber that is logged in the central Appalachians consists of low volume and value stands on steep, less accessible land. The question that has to be asked: Can this timber be logged with equipment that is often more expensive to operate than conventional ground skidding systems?

Topography is also important after the logs have been yarded to the spar. If the yarder is on a ridge top, logs can usually be dropped without sliding downhill, and they can be moved from beneath the skyline with a tractor or skidder. On midslope roads in steep country, there is usually insufficient decking space in front of the yarder and logs tend to slide down the slope. Where fixed towers are used, logs must be held by the yarder until they are secured by a cable from a tractor or skidder. In the West, hydraulic grapple loaders are used to remove logs from in front of the yarder. However, if yarders are equipped with swinging booms, logs can be swung and decked parallel to the road or on the road.

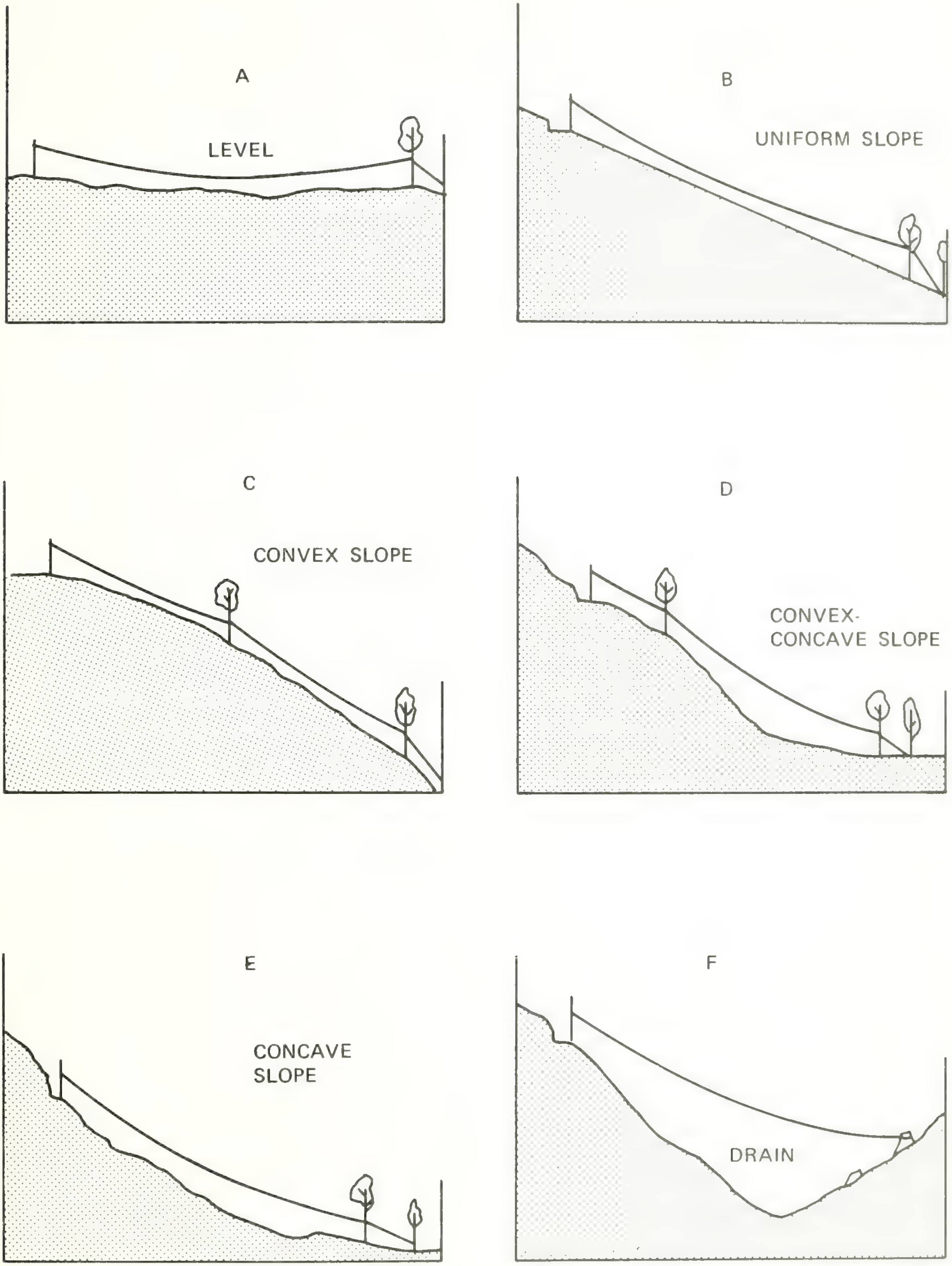


Figure 2.—Types of skyline situations.

Skyline Planning

Planning is an integral part of any logging job, regardless of the system used, but our experience and that of others has shown that cable systems demand more thorough planning than others (Burke 1975, Studier and Binkley 1974, Lysons and Wellburn 1976). The first step is to obtain the best topographic maps and aerial photographs available. From these, an access system and a rough logging show can be outlined. In the eastern United States, the U. S. Geological Survey 7½-minute quadrangle sheets which have a contour interval of 20 or 40 feet are readily available. Although they show none of the small obstructions such as rock outcrops and small benches, they are sufficiently detailed for determining road locations, landings, rough ground profiles, and corridor locations. The area should then be reconnoitered and roads, landings, and corridor locations flagged out.

Besides the topographic and environmental considerations, timber volume and value per acre are very important. The cut per acre must be carefully considered because it is probably the single most important variable that affects yarding costs. Most experience indicates that skyline logging, at least in partial cuts, is more expensive than conventional ground skidding (Aulerich and others 1974).

In the eastern United States, ownerships are relatively small and access to a given tract of timber is often controlled by property lines and topography. These characteristics of the tract to be logged must be considered when selecting the machine for the job. Mobility, rapidity of setup and tear-down, and ability to work from narrow roads are important factors to consider on small tracts.

Corridor Location

From the planning map and reconnaissance of the area, we can determine the number, length, and direction of corridors needed to harvest the various parts of the sale area.

Because topography changes over relatively short distances in the Appalachian mountains, we believe that most corridors longer than 400 or 500 feet will have to be laid out on the ground before logging when partial cutting is used. Mixtures of convex and concave slopes, frequent rock outcrops, and dense vegetation all limit visibility, which makes "eyeballing" corridor center lines difficult or impossible for long distances. In clearcuts, where preliminary information indicates that intermediate supports are not required, it seldom is necessary to mark corridor locations on the ground. Suitable tail trees are usually visible around the perimeter of the clearcut where there are no standing trees to interfere with passage of the carriage or tensioning of the skyline.

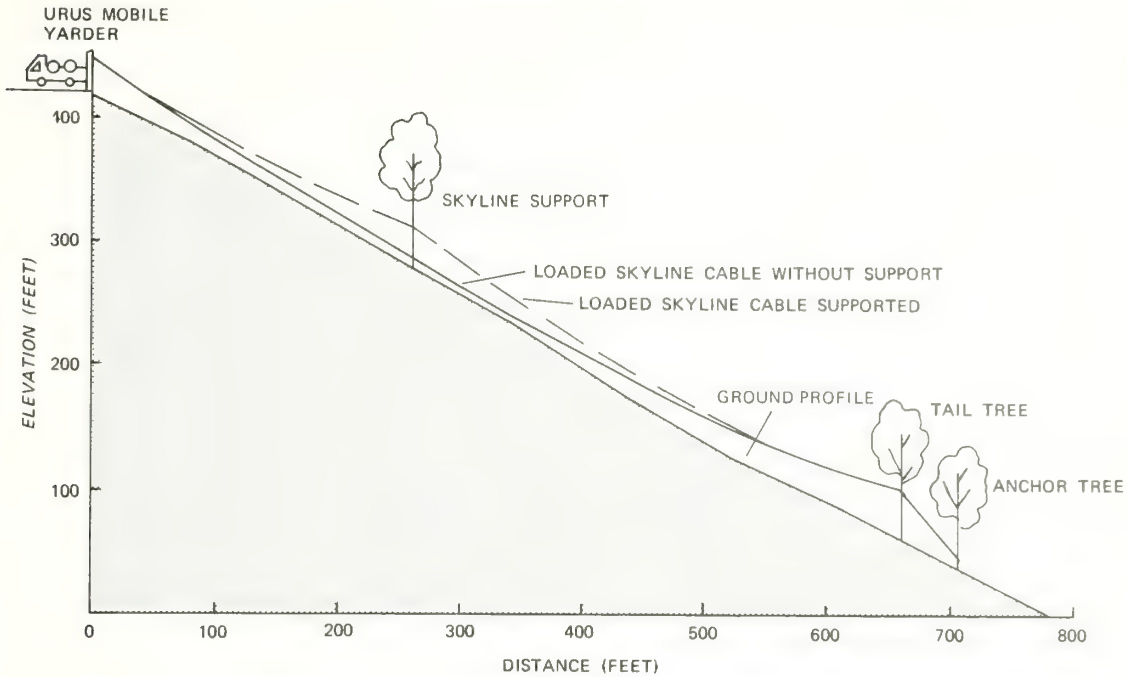
We have found that ground profiles of corridors can be made with a staff compass, 100-foot tape, and a surveying altimeter. An Abney level or clinometer can also be used to determine differences in elevation along the corridor. Field work is best done in the fall and winter when hardwoods have shed their leaves.

Suitable tail trees will seldom be found in line with the initial corridor centerline. If reference stations have been established on the original line, adjustments to the true line can be made by simple offset procedures. When adjustment of the original line is not necessary, the tail tree on the next corridor can be selected and the corridor centerline can be staked out going uphill. Frequently, however, rock outcrops or poor machine sites will require that this line also be adjusted. To complete the job, a stake is set to mark the location of the tower, the corridor centerline is flagged, and the tail tree and skyline anchor trees are flagged. When guylines are needed on the tail tree, guy trees are also flagged.

From the field survey notes the loaded skyline profile can be plotted over the ground profile by one of the available computer programs (Carson and others 1971). This plotting will indicate whether topography is a problem by showing the critical points along the loaded line, and where and how much the skyline must be elevated for logs to clear ground obstructions adequately (Fig. 3). If problems appear, the options previously mentioned can be used to overcome them.

In partially-cut stands, we observed that yarding hangups were less frequent when corridors were oriented at right angles to the contour. At less than right angles, logs on the uphill side of the skyline tend to roll behind trees and rocks when being yarded to the skyline. In clearcut areas, orientation of skyline corridors is less critical.

Figure 3.—Typical skyline profile on a relatively uniform slope.



Intermediate Supports

Although our tests with the URUS were not designed to study intermediate supports per se, we used them frequently and have a good idea of what they involve.

Intermediate supports add to the work of planning, laying out, and rigging for a skyline operation. The added work is about the same in clearcuts as in partial cuts. In both, corridor locations must be selected and support trees designated before cutting, because suitable support trees at the critical deflection points might otherwise be cut. When choice must be made, it is better to locate trees uphill from critical points. In rigging support trees, the blocks are normally hung about 25 to 30 feet high to obtain a clearance of 4 to 6 feet between the skyline and the ground when the skyline is loaded to capacity.

Only skyline systems that can be rigged as standing or fixed skylines can be used with intermediate supports. To our knowledge, supports have not been used with running skylines.

In planning a skyline cable operation where topography presents serious deflection problems, we have to consider whether the increase in skyline length obtainable by using intermediate supports can be justified. The major disadvantage of shortening corridor length, from 800 feet to 500 feet, is the increase in road density required to log a given area. It also reduces by about one-third the area logged per corridor. Where deflection permits longer spans to be efficiently logged without intermediate supports, costs can be spread advantageously over larger volumes. For example, the additional time needed to pull out an additional 500 feet of skyline is small compared to the increase in volume that might be obtained. If increasing span length means using one or more intermediate supports, then the additional work required to set them must be carefully evaluated. In addition to rigging time, the time in planning, skyline layout, location of critical points, and selection and designation of support trees must be included. Where environmental constraints severely limit road construction, long multispan skylines may be the only way timber can be harvested.

Timber Felling

Timber felling is most important for efficient skyline logging in partial cuts, less critical in clearcuts. Trees felled haphazardly or crisscrossed will hang up and slow the yarding operation when they are pulled toward the skyline. Whenever possible, trees should be felled downhill, at an angle of 25 or 30 degrees from the skyline corridor. This herringbone pattern is particularly important in partial cuts. In this position, logs are pulled more easily toward the skyline, with less side-strain on the system than if they are at greater angles. Usually, the higher the skyline (i.e. the greater the clearance between ground and skyline), the less critical timber felling becomes. With a high skyline, the hooked end of the log is raised above the ground sooner in lateral yarding, and the likelihood of its hanging up is reduced.

Choker Setting

In skyline logging where partial cutting is used, choker setting is probably the most important job. The choker setter must stop the carriage at a point on the skyline where logs hooked to it can move unobstructed toward the skyline, and cause a minimum of residual stand damage and site disturbance. Good communication must be maintained between the choker setters and yarder operator. After some experimentation, we found that portable remote control systems such as the Talkie-Tooter[2] worked well.

At first we used conventional cable chokers, but often they were too long and the front end of the log was not lifted above the ground. Then we tried chokers of various sizes, taking a couple of hitches around small logs, but it was always a problem to free the logs from obstacles and unhook. We finally settled on chain chokers which enabled us to hook the mainline within 3 or 4 inches of the log. These worked well except that yarding was usually limited to one log. Where clearance between the skyline and ground is a problem, 2 or 3 more feet of lift on the front end of the log can eliminate many hangups during yarding.

Skyline Rigging

Rigging a standing skyline such as the URUS consists of guying the tower, hanging a block in the tailtree, guying the tailtree (if necessary), and tying the skyline to an anchor tree or stump. If intermediate supports are required, the rigging includes a block in each of two trees (one on each side of the skyline), guying these trees, hoisting the intermediate supports with a portable winch, and tying-off the support cable (Fig. 3). Intermediate supports should hold the skyline at least 15 feet above the ground.

Another problem in rigging is to find suitable tail and support trees; usually over 14 inches dbh, well-anchored, and with no visible rot in the stem or upper bole. They must have 20 to 30 feet of clear stem and be climbable with tree spurs or a ladder. Ideally, intermediate support trees should be 20 to 30 feet apart, and on about the same contour level. Guy trees can be somewhat smaller, probably not less than 12 inches at the stump, where most guylines will be tied off. Otherwise, these trees should possess the same characteristics as tail and support trees.

In the URUS tests, we hung the tail block about 30 feet above the ground. Tree climbing ladders worked best for our crew but we see no reason why climbing spurs cannot be used. Ladders are cumbersome to move from one corridor to another, especially across cut-over areas.

Cable logging requires a high degree of practical engineering know-how and skill; people with this ability are needed to make systems such as the URUS workable. Shorter skyline spans (500 feet maximum) and machines with spars of 40 feet or more can simplify the rigging job by eliminating intermediate supports. Also, cable logging probably is more strenuous than conventional logging because heavy loads often must be carried down steep slopes for 600 to 800 feet. There is no dense road system, as there is in conventional logging, to walk or drive on. Rigging would be easier if roads were spaced to give access to taitrees or perhaps even allow the use of mobile tail spars.

Some Thoughts on a Skyline System for the East

Two years' experience with the URUS and observation of other cable systems in the eastern and western United States provides us some insight as to the kind of machine best suited for the Appalachian mountains. Because eastern ownerships are small, and rights-of-way are often difficult to obtain, the machine should be highly mobile and able to negotiate steep, narrow roads (12 to 14 feet wide). If the machine is mounted on rubber tires rather than tracks, short moves over public roads can be made without loading it on a lowboy.

The size of the machine is another important consideration. Many bridges in the East have weight limitations, so the machine weight should not exceed 70,000 pounds. The cost of a machine, of course, varies with its size, but we believe that the cost will have to be less than $100,000 if the average eastern contract logger is expected to purchase one.

The machine should have a swinging boom so that logs can be decked parallel to the road or dropped in the road behind the yarder. This is safer for the crew and logs can be cold-decked, if necessary.

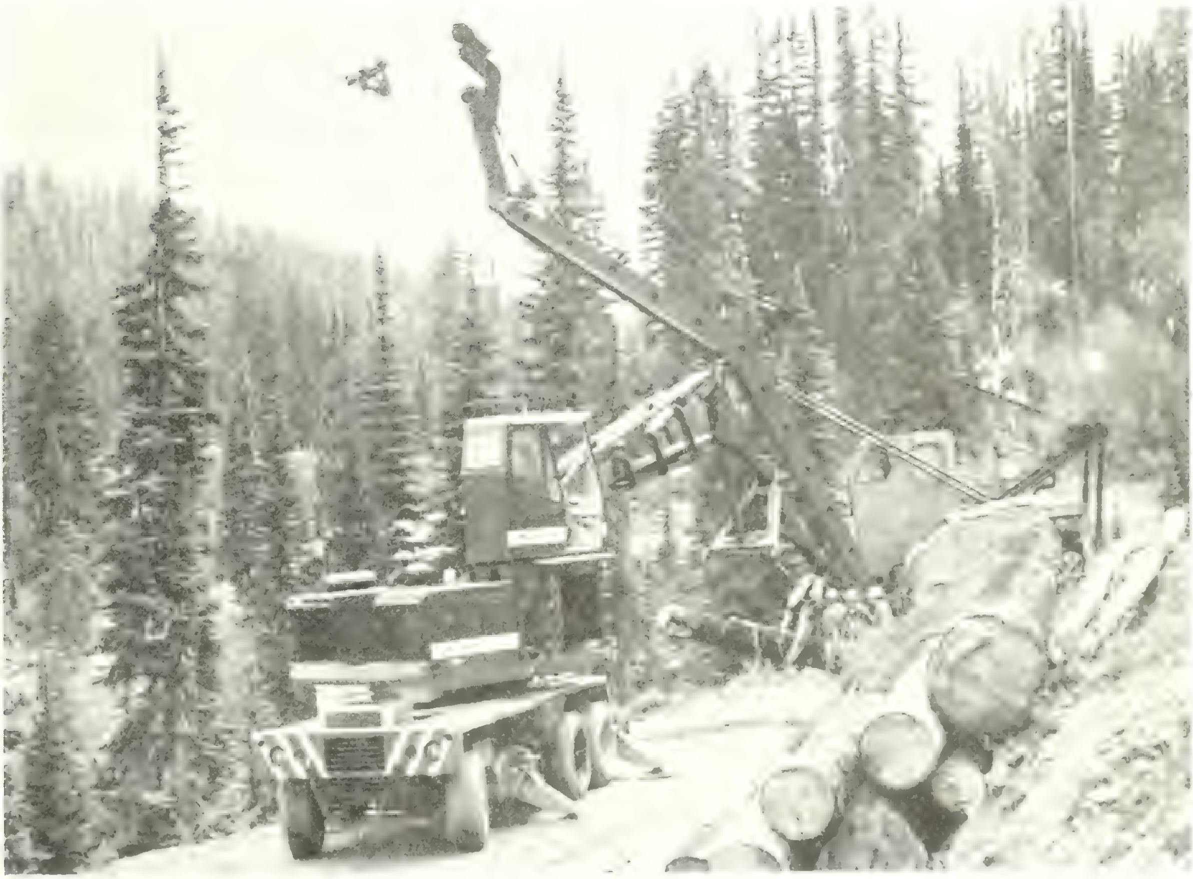
Since setup and tear-down times are important components of cost, we believe the machine should be equipped with hydraulic guyline winches and hydraulic outriggers for leveling. In addition, the machine should have a mainline speed of 1,000 feet per minute and be operable with four men or less.

In the West, the least volume removed in thinnings was about 6 M bm/acre. The stumpage value of this material is similar to our hardwood values. Most eastern hardwood stands are harvested using some partial cutting system, and usually they will only support a cut of about 4 to 6 M bm/acre every 20 to 30 years. If skyline cable logging is feasible under these conditions, we feel that some of the machines used in the West for thinning (Fig. 4) might be of suitable size and cost for logging in the East.

The machines used for thinning small material (10 to 20 inches dbh) in the West are much larger than we had envisioned. Even though most material logged in the East is in this size range, hardwoods weigh about one-third more per cubic foot than western conifers. We feel that a machine should be rugged and capable of yarding a 10,000 pound load. Failures in our system always occurred when hangups caused maximum loads on the system.

In our opinion, a running or live skyline system

Figure 4.—A converted shovel at work in the western United States.



would best suit our needs—a machine capable of lowering or raising the skyline at will. These systems permit the use of simple, more rugged carriages. Carriages that lock automatically require more care and adjustment, and are less able to withstand day-to-day hard use. Simple, rugged slack-pulling carriages that can yard logs laterally from 100 feet on either side of the skyline are necessary for partial cutting. Running skyline systems usually have slack-pulling devices; the simpler systems, such as the live or shotgun, employ simpler carriages with manual slack pulling. Running skylines are the most versatile systems known today (Lysons and Twito 1973; Burke 1975), but we feel that cost of the available ones is prohibitive for most eastern operations.

The equipment should have the capability to yard from distances of at least 1,000 feet. Even though we visualize most spans in the 400- to 600-foot range, there are situations, such as across hollows or concave slopes, where the longer capability would be desirable.

Another feature to consider is the equipment's ability to log downhill. Theoretically, if you could log 500 feet uphill and 500 feet downhill, roads could be spaced 1,000 feet apart. However, downhill yarding has not gained wide acceptance. Most experienced loggers feel that its problems (for example, controlling the turn of logs and keeping them from rolling behind trees) were too great to overcome. It would be dangerous and impractical on midslope roads because it would require yarding over cut banks, and logs would be likely to roll. A running skyline system is probably best for downhill yarding, but yarders that have this capability are more complex and costly than systems that use gravity-powered carriages.

In summary, the combinations of timber volume and value in the East probably will not support the more sophisticated yarding systems used in the West. Until more suitable equipment is developed, a live skyline system with skyline and mainline drums and a gravity carriage seems most acceptable. It should be highly mobile and capable of yarding up to 1,000 feet. It should have a mainline speed of about 1,000 feet per minute and should be operable by a 4-man crew. It should have hydraulic guy winches, hydraulic outriggers for leveling, and a 40- to 45-foot "swing boom" tower. Even with these desirable features, it remains to be proven that skyline systems are an economically viable alternative to existing ground skidding systems in the East.

Glossary
(Cable Logging)[3]

Carriage.—A wheeled device that rides back and forth on the skyline for yarding or loading.

Choker.—A noose of wire rope or chain for hauling a log.

Cold-deck.—An area where yarded or skidded logs are stored prior to hauling to the mill.

Corridor.—The path cleared to allow passage of the carriage and logs when yarding in partial cuts or thinnings.

Corridor length.—The cleared corridor distance between the tower and tailtree or skyline anchor.

Deflection.—The vertical distance between the chord and the skyline, measured at midspan—frequently expressed as a percentage of the horizontal span length.

Gravity feed.—Skyline system which depends on gravity to pull the carriage down the skyline.

Ground skidding.—Movement of the log from the stump to landing with a wheeled or tracked machine.

Guy.—A rope, chain, or rod attached to something to brace, steady, or guide it.

Guy tree.—A tree used to anchor a guy.

High-lead.—A cable logging system in which lead blocks are hung on a spar to provide lift to the front end of the logs.

Intermediate support or skyline jack.—A device that supports the skyline at an intermediate point.

Intermediate support tree.—Tree(s) located between the tower and tailtree to support an intermediate support or skyline jack.

Jammer.—A light weight, two-drum yarder, usually mounted on a truck with a spar or boom—may be used for both yarding and loading.

Live skyline.—A standing skyline that can be raised and lowered during yarding.

Main line.—The hauling cable.

Multispan skyline.—A skyline having one or more intermediate supports.

Rigging.—The cables, blocks, and other equipment used in yarding logs.

Running skyline.—A system of two or more suspended moving lines, generally referred to as main and haulback, that when properly tensioned will provide lift and travel to the load carrier.

Skyline.—A cableway stretched tautly between two spars and used as a track for log carriers.

Skyline anchor.—Usually a tree or stump located behind the tailtree, when one is used to anchor the skyline.

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[3] Adapted from Glossary of cable logging terms, U.S. Dept. Agric. For. Serv. Pac. Northwest. For. Range Exp. Stn. Portland, Ore. (1969), and Cable logging systems (Studier and Binkley 1974).

Skyline block.—A block on the tailtree that the skyline runs through.

Skyline length.—The amount of line suspended between the headspar and skyline anchor.

Skyline logging.—A logging method in which a block or carriage rides on a skyline.

Span.—The horizontal distance between the headspar or anchor point, and the tail spar or anchor point.

Spar.—The tree or mast on which rigging is hung for one of the many cable hauling systems.

Standing skyline.—A skyline anchored at both ends.

Straw line.—A light cable used to string heavier lines.

Straw drum.—A small drum on yarders; handles the straw line.

Tailtree.A spar at the outer end of the skyline logging operation, away from the landing.

Tower.—A steel spar attached to the yarder used to support the skyline and other rigging.

Yarder.—A system of power-operated winches used to haul logs from a stump to a landing.

Yarding.—The act or process of conveying logs to a landing. In our opinion, it is more consistent with accepted terminology to restrict the term "yarding" to the conveying of logs with cable systems. "Skidding" refers to dragging logs behind animals or machines traveling on the ground.

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by Raymond E. Graber and Donald F. Thompson

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SEEDS IN THE ORGANIC LAYERS AND SOIL OF FOUR BEECH-BIRCH-MAPLE STANDS

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Abstract

Forest floor samples were collected in northern hardwood stands 5, 38, 95, and 200+ years old. The seeds contained in these samples were germinated in a greenhouse. Thirty-five species of herbs, shrubs, and trees were identified. The largest number of species, 23, were from the 5-year-old stand. The oldest stand had the fewest species, 17. *Rubus* and pin cherry (*Prunus pensylvanica* L.f.) were the most numerous of the buried seeds. Their total numbers were highest in the 5- and 38-year-old stands and much lower in the older stands. The current practice of timber harvesting at rotations of 100 years or more results in moderate densities of these plants. If short rotations are used, the increased densities of these species may require intensive silviculture practices to ensure adequate stocking of the high-value timber species.

INTRODUCTION

THE BEECH-BIRCH-MAPLE forest of the White Mountains of New Hampshire is a plant community with numerous checks and balances that help retain its natural stability. When the mature forest is harvested or destroyed, a secondary succession of shrubs and short-lived trees starts the process that will culminate in a high forest once again (Marks 1974). The typical regeneration sequence after the removal or destruction of a beech-birch-maple forest includes the early establishment of most of the species found in the mature forest. Woody shrubs such as *Rubus*[1] quickly dominate many sites, reaching a peak development in 2 to 5 years. Pin cherry ordinarily overtakes *Rubus*, and is in turn dominated by paper and yellow birch within 20 to 30 years after the disturbance. From this point, the mid- and late-successional species—red maple, white ash, sugar maple, and beech—become more important with each passing decade.

The rapid replacement of the harvested or destroyed forest by a secondary succession of short-lived woody species serves the important functions of conserving the soil and plant nutrients and stabilizing the soil until the more slowly developing high forest species again dominate the site.

The seed of some species that dominate New England forests in the first years after disturbance are present in the litter and soil before the overstory is removed (Frank and Safford 1970, Livingston and Allessio 1968, Marks 1974, Olmsted and Curtis 1947). Marquis (1975) has found a relationship between numbers of buried seed and stand age in Pennsylvania. But we know very little about the numbers and species of buried seeds in the beech-birch-maple forest, and especially about how this seed population changes over long periods of time. The purpose of this study was to determine the numbers and species of buried seeds in forest stands of widely differing ages.

METHODS AND MATERIALS

Four stands in the White Mountain National Forest were selected for this study:

(1) A 5-year-old northern hardwood stand that developed following the clearcutting of a mature beech-birch-maple stand in 1967 (Fig. 1).

(2) A 38-year-old northern hardwood stand that developed following the clearcutting of an old-growth beech-birch-maple stand in 1934 (Fig. 2).

(3) A mature beech-birch-maple stand 95 years old (Fig. 3). There was heavy cutting in this area in the early 1870s when red spruce and better quality hardwoods were removed.

(4) An undisturbed climax beech-birch-maple stand (Fig. 4). This virgin stand has had no major natural disturbance in more than 200 years.

Species composition was measured in the four stands. Basal area data were collected in the three older stands (Table 1a). Fresh-weight biomass data were used to measure composition in the 5-year-old stand (Table 1b).

In each stand, at 20 points selected at random, samples of the forest floor were collected. The material was dug from pits 22.36 cm^2 (8.8 in^2) and carefully divided into three groups: combined litter and fermented layers (L-F); the humus layer (H); and the upper 5 cm (2 in) of mineral soil (M). The material in each group from each stand was spread out in separate 30 cm^2 (11.8 in^2) flats (Fig. 5). The flats were placed in a greenhouse and irrigated with a misting system to provide conditions favorable for germination. Each seed that germinated was marked, grown until it could be identified, and then discarded. The greenhouse was screened so that no local seed could fall into the flats. The experiment was maintained in the

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[1] Common and scientific names are listed in Table 2.

Figure 1.—Five years after the old-growth beech-birch-maple was clearcut, samples were taken from the forest floor under this young stand dominated by pin cherry. Little remains of the dense *Rubus* of earlier years.

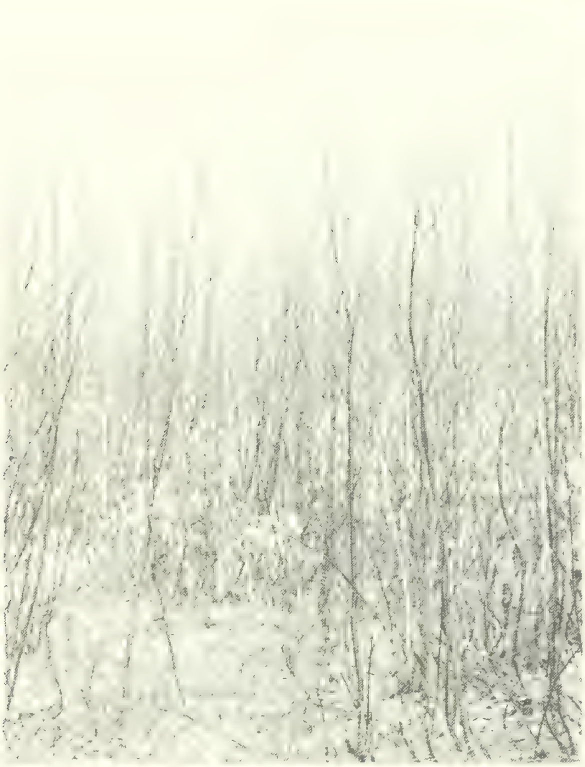


Figure 2.—This stand, dominated by paper birch, developed after clearcutting 38 years ago. Most of the pin cherry (the dark stems in the foreground) are dead or dying.

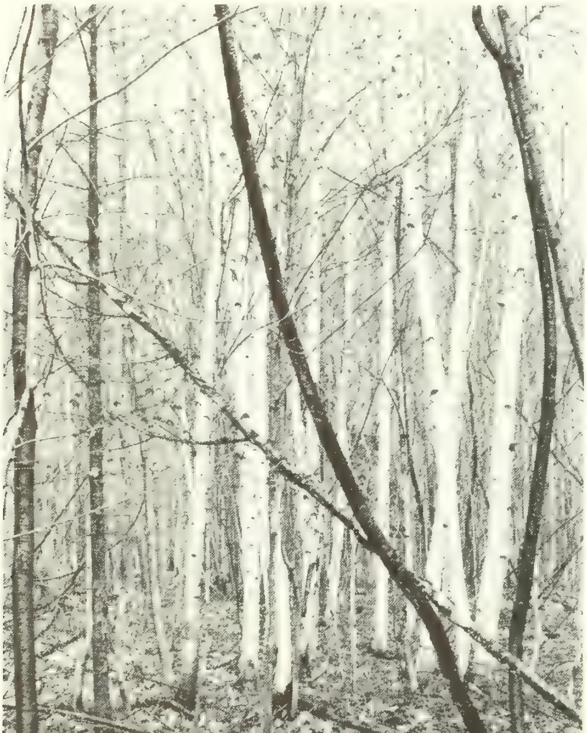


Figure 3.—There was very heavy cutting in this stand 95 years ago. The major species now are beech, red maple, white ash, and yellow birch. The paper birch is decadent and will die out completely during the next 10 to 20 years.

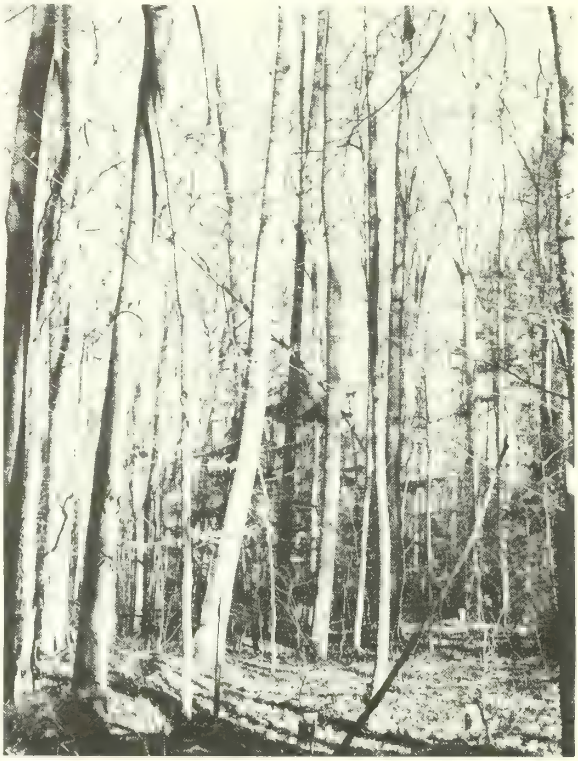


Figure 4.—This virgin forest has been undisturbed for over 200 years. The only tree species present are sugar maple, beech, yellow birch, and an occasional striped maple.

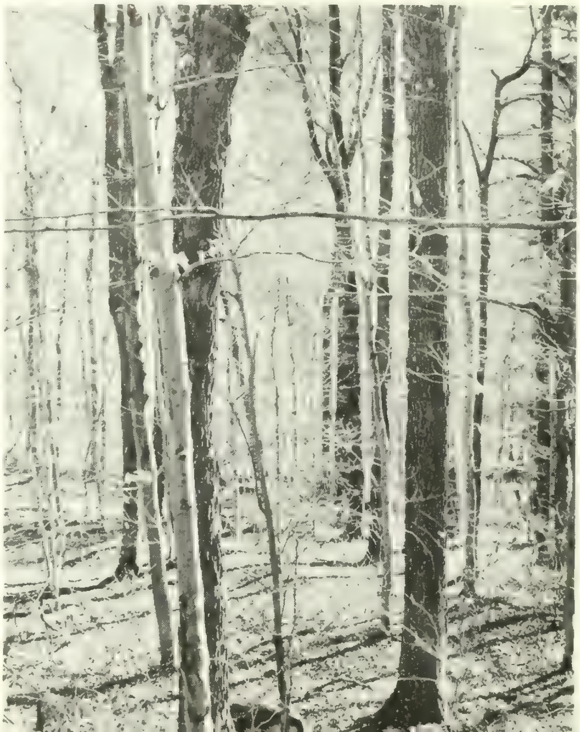


Table 1a.—Species composition as a percentage of total stand basal area (150 mm dbh and larger)

Stand age	Species										Total basal area
	Large-tooth aspen	Pin cherry	Striped maple	Paper birch	Red maple	White ash	Beech	Sugar maple	Yellow birch	Eastern hemlock	
Years	*Percent*										*m²/ha*
38	8.6	7.8	0.8	47.6	1.6	0.8	10.9	8.6	13.3		23.4
95				6.1	20.1	15.3	42.8	4.8	9.6	1.3	35.7
200+							40.0	50.5	9.5		50.6

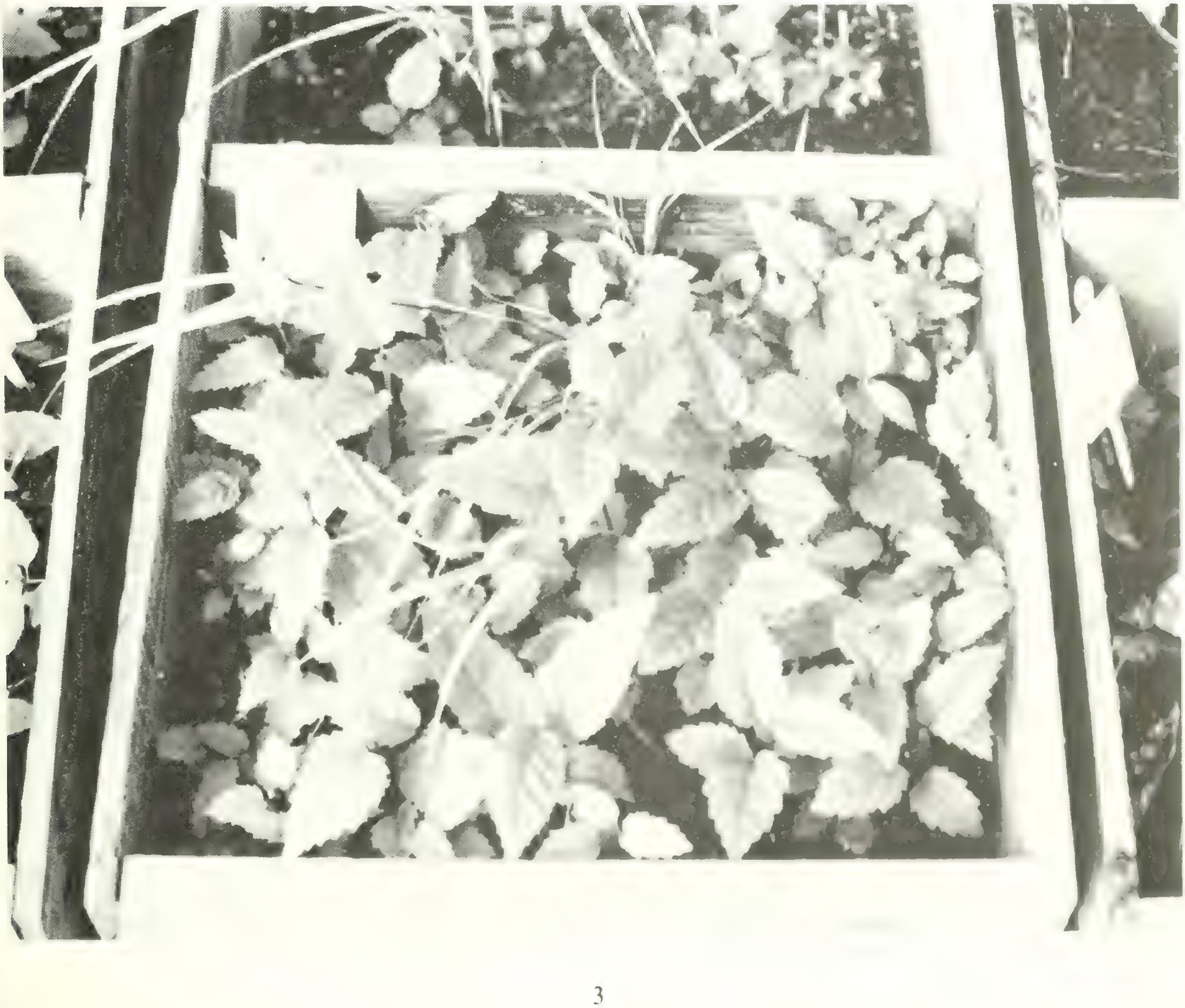
4.356 × m²/ha = ft.²/acre.

Table 1b.—Species composition as a percentage of above-ground biomass (fresh weight)

Stand age	Species										
	Pin cherry	Striped maple	Paper birch	Yellow birch	Sugar maple	Beech	*Rubus*[a]	Red-berried elder	Hobble-bush	Yew	Misc.
Years	*Percent*										
5	41.9	9.9	9.4	5.6	3.6	2.9	14.8	6.1	3.5	1.3	1.0

[a] In this paper, *Rubus* includes *R. idaeus* and *R. allegheniensis*.

Figure 5.—A 30 cm² greenhouse flat containing the litter and fermented layer from the 200 + year-old stand. Seedlings of yellow birch and an unidentified grass predominate.



unheated greenhouse through three growing seasons and two winters.

Analysis of variance was used to evaluate the data after transformation to fit normality assumptions. A separate analysis was done for each major species. Among species, comparisons of numbers of germinating seeds were made using Duncan's new multiple range test.

RESULTS AND DISCUSSION

Seeds of 35 species germinated and grew in the forest floor samples (Table 2). The greatest number of species germinated in samples from the 5-year-old stand, with 23 identified plus several unidentified grasses, sedges, and a rush. In the 38-year-old stand, there were 20 species identified

Table 2.—Germinating seeds per m² in forest floor samples from four beech-birch-maple stands

Species		Stand age (years)				Total
		5	38	95	200 +	
Herbs						
Shining club-moss	*Lycopodium lucidulum* Michx.	—	1	1	1	3
Grass[a]	Gramineae	53	—	7	5	65
Sedge[a]	*Carex* L.	117	1	—	2	120
Rush[a]	*Juncus* L.	1	—	—	—	1
Wild-oats	*Uvularia sessilifolia* L.	—	—	—	1	1
Sweet white violet	*Viola blanda* Willd.	7	2	2	2	13
Round-leaved violet	*Viola rotundifolia* Michx.	—	—	—	78	78
Purple-leaved willow-herb	*Epilobium coloratum* Biehler	3	—	—	—	3
Northern willow-herb	*Epilobium glandulosum* Lehm.	90	—	2	—	92
Narrow-leaved willow-herb	*Epilobium leptophyllum* Raf.	1	—	—	—	1
Small enchanter's night shade	*Circaea alpina* L.	5	—	—	—	5
Rough-stemmed goldenrod	*Solidago rugosa* Ait.	15	—	—	—	15
Canada goldenrod	*Solidago canadensis* L.	73	—	—	—	73
Narrow-leaved goldenrod	*Solidago graminifolia* (L.) Sabisb.	35	1	—	—	36
Whorled wood aster	*Aster acuminatus* Michx.	4	1	—	—	5
Pilewort	*Erechtites hieracifolia* (L.) Raf.	1	—	—	—	1
Spikenard	*Aralia racemosa* L.	1	7	—	1	9
Birstly sarsaparilla	*Aralia hispida* Vent.	—	2	—	—	2
Wild sarsaparilla	*Aralia nudicaulis* L.	1	—	1	—	2
Total		407	15	13	90	525
Number of species		12	6	4	5	
Shrubs						
Long-beaked willow	*Salix bebbiana* Sarg.	—	2	2	1	5
Meadow-sweet	*Spiraea latifolia* (Ait.) Borkh	13	2	5	—	20
Raspberry	*Rubus idaeus* L.	1016	286	68	12	1382
Blackberry	*Rubus allegheniensis* Porter	31	166	21	—	218
Bush-honeysuckle	*Diervilla lonicera* Mill.	1	1	8	1	11
Red-berried elder	*Sambucus pubens* Michx.	42	25	3	69	139
Total		1103	482	107	83	1775
Number of species		5	6	6	4	
Trees						
Balsam fir	*Abies balsamea* (L.) Mill.	—	—	1	—	1
Eastern hemlock	*Tsuga canadensis* (L.) Carr.	—	—	1	—	1
Quaking aspen	*Populus tremuloides* Michx.	1	124	—	2	127
Large-toothed aspen	*Populus grandidentata* Michx.	13	174	8	5	200
Yellow birch	*Betula alleghaniensis* Britt.	181	144	961	1460	2746
Paper birch	*Betula papyrifera* Marsh.	87	1340	445	20	1892
Mountain paper birch	*Betula cordifolia* Regel	—	—	—	18	18
American beech	*Fagus grandifolia* Ehrh.	—	—	—	4	4
Pin cherry	*Prunus pensylvanica* L. f.	2	111	52	1	166
Striped maple	*Acer pensylvanicum* L.	3	1	—	—	4
Sugar maple	*Acer saccharum* Marsh.	—	2	4	123	129
Red maple	*Acer rubrum* L.	—	—	10	—	10
White ash	*Fraxinus americana* L.	—	7	10	—	17
Total		287	1903	1492	1633	5315
Number of species		6	8	9	8	
Unknown		32	9	3	2	46

[a] Species not identified for this group and not counted in totals for number of species.
Seeds/m² ÷ 10.76 = Seeds/ft.²

and a single unidentified sedge. The 95-year-old stand had 19 species, and the 200+ year-old stand had 17 species; both stands had unidentified grasses. In addition, unknown plants germinated in the litter and soil from the four stands. These unknowns died before they were mature enough to be identified. Total germination in the samples ranged from 16 million to over 24 million per hectare in the four stands (Table 3).

Delayed germination

The samples were maintained 3 years in the greenhouse so that dormant seeds would have an extended opportunity to germinate. Most of the germination (92.7 percent) took place the first summer. Germination was 99.6 percent complete at the end of the second growing season. *Rubus* from the 5-year-old stand and pin cherry from the 38- and 95-year-old stands accounted for almost all of the second- and third-year germination (Table 4).

During the first summer, more than 90 percent of the *Rubus* seeds germinated in samples from the 38-, 95-, and 200+ year-old stands, while only two thirds of *Rubus* from the 5-year-old stand germinated. Apparently some of the seeds from the 5-year-old stand were dormant and required an extended period for germination. These seeds had been produced and deposited beneath the parent *Rubus* since the clearcut 5 years earlier. *Rubus* seeds stored for longer periods (e.g., in the 38- and 95-year-old stands) exhibited very little delayed germination. The proportion of dormant *Rubus* seeds may be time-dependent, with most of the seeds ready to germinate at a stand age between 5 and 38 years.

Table 3.—Total number of seedlings germinating per hectare in the organic layers and soil collected in the beech-birch-maple stands

Stand age (years)	Seedlings
5	18,290,000
38	24,090,000
95	16,150,000
200+	18,080,000

Seedlings/ha ÷ 2.471 = seedlings/acre.

Table 4.—Cumulative germination of *Rubus*, pin cherry, and all other species, as a percentage of total germination

Year of germination	Stand age (years)			
	5	38	95	200+
		Rubus		
First	66.5	98.0	96.6	91.7
Second	98.5	100.0	100.0	91.7
Third	100.0	100.0	100.0	100.0
		Pin cherry		
First	0	73.9	71.7	100.0
Second	100.0	100.0	100.0	100.0
Third	100.0	100.0	100.0	100.0
		All others		
First	97.8	97.7	95.8	98.8
Second	99.3	100.0	100.0	100.0
Third	100.0	100.0	100.0	100.0

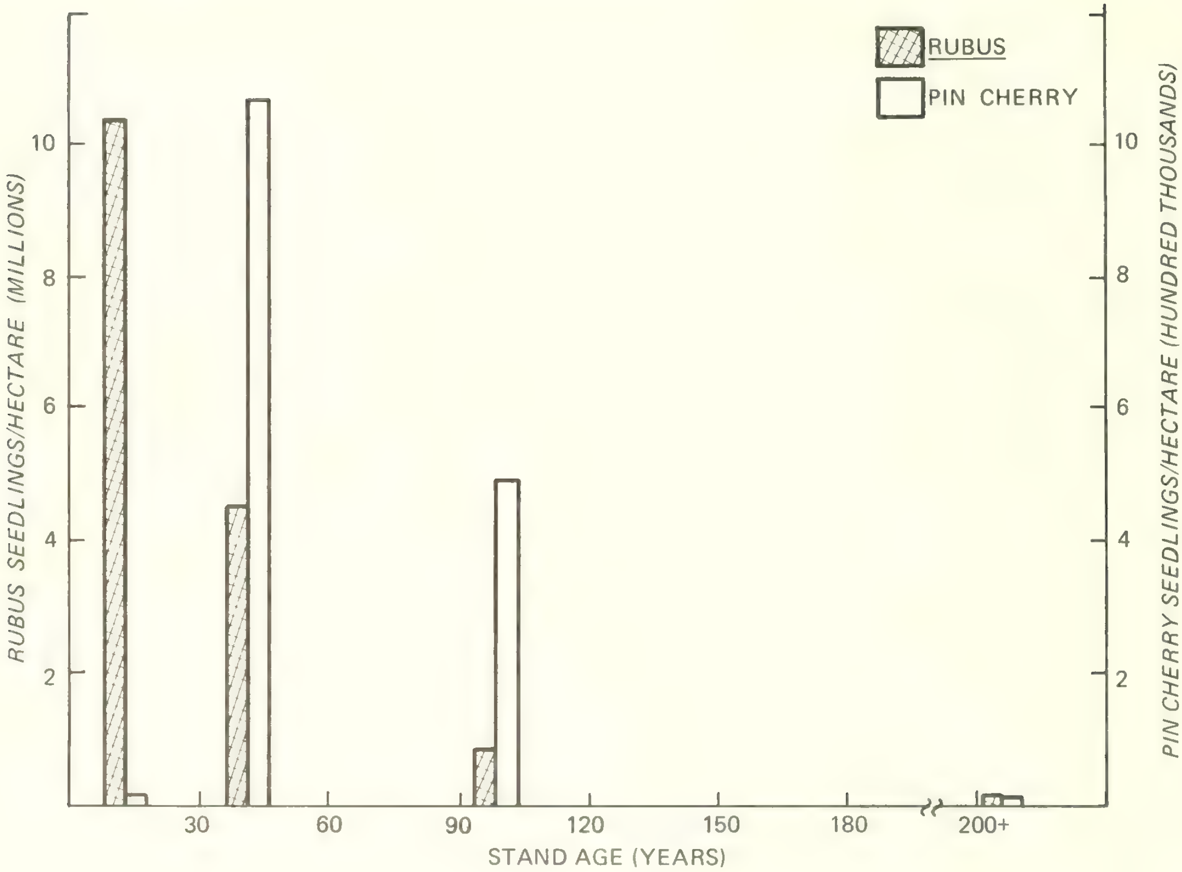
Pin cherry germination reached 73.9 percent in samples from the 38-year-old stand and 71.1 percent in samples from the 95-year-old stand during the first summer. Germination was completed the second summer. Too few pin cherry seeds germinated in samples from the 5-year-old and 200+ year-old stands to indicate any trends.

Stand age

The four stands were growing on fairly typical northern hardwood sites. The chief difference among the stands was length of time since a major disturbance. The number of germinating *Rubus* and pin cheery seeds differed significantly ($p < 0.05$) among the four stands (Fig. 6). Seeds of *Rubus* were present in very large quantities in the youngest stand but the number dropped rapidly in the old stands, falling from more than 10 million per ha in the 5-year-old stand to 120,000 per ha in the 200+ year-old stand. Three basic causes of this dramatic reduction in viable *Rubus* seeds are: (1) the natural time-dependent degeneration that culminates in seed death, (2) losses due to bacteria, fungi, and predation by birds, small mammals, and insects, and (3) the annual germination of some of the buried seeds. To further complicate the situation, birds transport additional seeds annually. Seed-fall data (collected for another study on these same plots) indicated these annual deposits to be 6,000 to 7,000 viable *Rubus* seeds per hectare. We believe that the few germinating *Rubus* seeds from the 200+ year-old stand were deposited by birds and were not an artifact of the early succession. We estimate the maximum age of viable *Rubus* seed to be 50 to 100 years.

The pin cherry seed supply peaked at a later age. Pin cherry matures rapidly, dying off at 20 to 40 years of age, and it is logical that there would be the maximum buried seed supply as the tree

Figure 6.—Germinating pin cherry and *Rubus* seeds stored in the forest floor.



reached maturity. The causes of pin cherry seed depletion are the same as for *Rubus*. The number of pin cherry seeds found in the 95-year-old stand was high, indicating a long life for this species.

We have evidence that very few pin cherry seeds are deposited by birds in the 95- and 200+ year-old stands. In 6 years of monitoring seed fall, not a single pin cherry seed has been found. Our estimate of maximum longevity for pin cherry seeds is 75 to 150 years.

Seed depth

Much of the germination took place in the upper organic layer of the forest floor (Fig. 7). Germination of the L-F layer ranged from 57.7 percent in the youngest stand sampled to 88.0 percent in the 95-year-old stand. The seeds germinating in this layer were representative of the overstory. They were primarily the wind-disseminated birch, aspen, and maple seeds, with one exception. In the 5-year-old stand, tree seed production was just beginning (e.g., pin cherry), and most of the germination in the L-F layer samples was *Rubus* and various herbs typical of the early successional plant cover. The birch seeds present were blown in from trees on the perimeter of the 5-year-old clearcut.

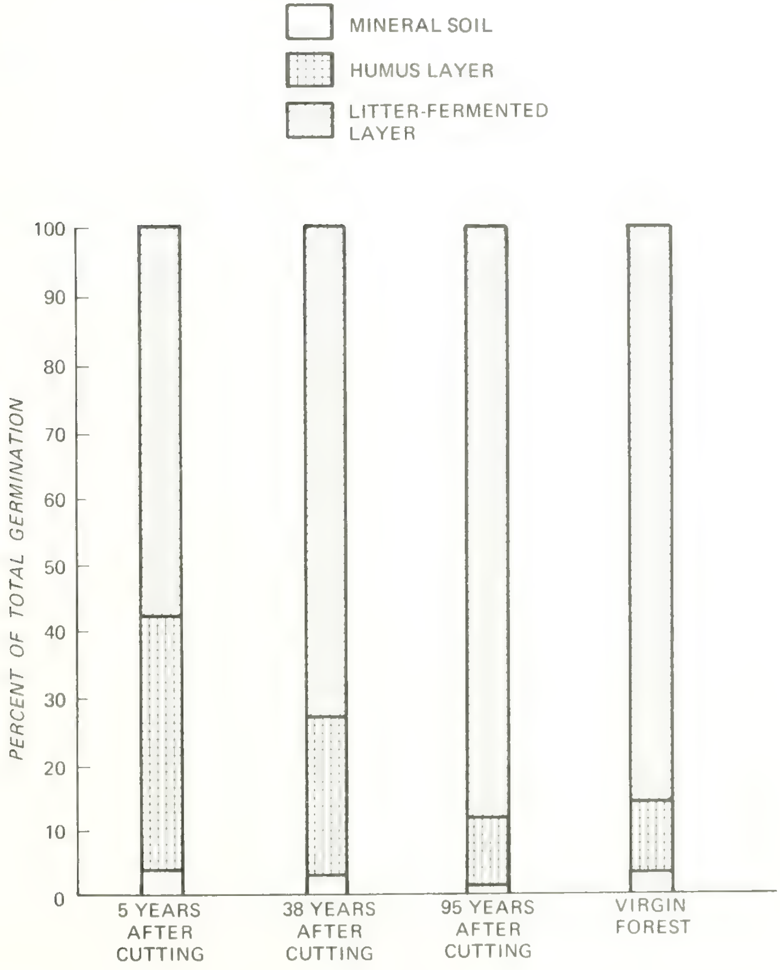
The proportion of total germination in the H layer samples declined from 37.9 percent in the 5-year-old stand to 10.3 percent in the 200+ year-old stand. Since most of the long-lived buried seeds are in this layer, a change in viable seed numbers here would influence species composition and density in any secondary succession triggered by clearcutting or natural calamity.

Germination in the mineral soil samples also appeared to be related to stand age. There was a reduction in the percentage of germination from the 5- to 95-year-old stand. However, this trend was reversed in the 200+ year-old stand. At least 75 percent of the seed germinating in the soil from the three younger stands was pin cherry and *Rubus*. In the 200+ year-old-stand samples, there was no pin cherry and less than 8 percent *Rubus*. The most numerous species in the mineral soil of this very old stand were round-leaved violet (57 percent) and red-berried elder (26 percent).

Round-leaved violet plants were common in the 200+ year-old stand and absent in the other three stands. This violet blooms early in the spring before the trees leaf out, and produces some fresh seed each year. The seed has a hard coat and may survive for years in the forest floor.

The presence of red-berried elder seed is more difficult to explain. Our data (Table 2) show the equivalent of 420,000 red-berried elder seeds per ha germinating in the 5-year-old stand, and a decline to only 30,000 in the 95-year-old stand. The equivalent of 690,000/ha germinated in the samples from the 200+ year-old stand. A number of stunted red-berried elder plants of low vigor were noted in the understory of this stand. None of these understory plants has flowered or fruited in the past 5 years. In 1970 and 1971, there was a severe defoliation by the saddled prominent (*Heterocampa guttivitta* (Wlkr.)), and flowering and some seed production by red-berried elder was observed in adjacent areas. However, no visit was made to the collection site during that period, and we do not know if seed was produced there. We suspect that viable red-berried elder seeds are stored in the forest floor for one or more decades. Birds are voracious consumers of red-berried elder fruit and probably distribute the seed widely, but in small quantities. We have never collected, in

Figure 7.—Depth of germinating seeds in organic layers and soil from the four northern hardwood stands.



seed traps, a single-red berried elder seed that could be attributed to dispersal by birds. The saddled prominent causes large-scale defoliation at about 30-year intervals. This periodic defoliation may be sufficient to ensure fruiting and survival of some red-berried elder seeds in the forest floor.

CONCLUSIONS

Seed numbers and species differed in important ways among the four stands. The greatest number of species germinated in samples from the 5-year-old stands. Delayed germination was also most common in this young stand, largely due to the natural dormancy of the newly deposited *Rubus* seeds. The number of seeds germinating in the humus and soil of the 95-year-old and 200+ year-old stands was only one-third of that in the two younger stands. This reduced germination is a reflection of the decline in all seeds, but especially in *Rubus* and pin cherry seeds.

This pattern of viable seed survival could have an important bearing on future even-age management practices. Currently, many northern hardwood stands in New England are harvested at ages of 100 years or more, when the stored supplies of *Rubus* and pin cherry seeds are relatively low. As resource managers attempt to extract greater yields from our forests, they may of necessity resort to shorter rotations. When stands are harvested at lower ages, the dense populations of pin cherry and *Rubus* are likely to cause intense competition for growing space.

Competition for light, moisture, and nutrients may limit the stocking and development of commercial species, particularly paper birch, yellow birch, and white ash. Wilson and Jensen (1954) reported poor stocking after a 60-year-old northern hardwood stand on the Bartlett Experimental Forest was clearcut. They concluded that the timber species could not compete with the rank growth of *Rubus* and pin cherry that followed the harvest.

It is likely, then, that short rotations in the beech-birch-maple forest will require intensive silvicultural practices on some sites to control *Rubus* and pin cherry to retain adequate stocking of the high-value timber species.

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CONSUMER PREFERENCE FOR GRADED MAPLE SYRUP

by Paul E. Sendak

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Abstract

The three grades of maple syrup and a commercial table syrup containing artificial flavor and 3 percent pure maple syrup were evaluated by 1,018 women in four cities. The results indicate that differences in preference for flavor are related to how close the respondents are to a maple syrup-production region. Differences in preference among grades of pure maple syrup were slight and in reverse order of the quality implied by the Federal grading standard. Outside of the region of maple syrup production, differences in preference between pure maple syrup and the commercial table syrup were marked, and favored the commercial syrup.

INTRODUCTION

Do USERS prefer pure maple syrup to a national brand of artificially flavored table syrup? Does syrup preference depend on whether a person has used pure maple syrup? This study was designed to measure consumer preferences among the three grades of maple table syrup and a national brand of artificially flavored table syrup. The study used paired products testing. Data were gathered on the participants' evaluations of the syrups before and after use, on their pattern of syrup use, and on their age, household size, and income.

METHODS

There are three Federal maple table syrup grades.[1] They are based on the relationship between syrup color and flavor. U.S. Grade AA syrups are light amber and have a delicate bouquet with a detectable base maple flavor. U.S. Grade A syrups are medium amber and have the base maple flavor. U.S. Grade B syrups are dark amber and have a caramel flavor. The national brand of table syrup used in this study was Log Cabin (LC).[2] This syrup contains cane and corn syrups, artificial flavoring, coloring, preservatives, and 3 percent maple sugar syrup.

About 100 gallons of each of the three grades of maple syrup were thoroughly mixed, filtered, and then hotpacked (180°F) in clear glass pint bottles. The table syrup was also hotpacked in the same type of bottle. Each bottle was identified by a three-digit code on a white label.

Study participants were selected from four metropolitan areas. Two of the areas—Lansing, Mich., and Manchester, N.H.—are within the maple syrup-producing region; the other two areas—Colorado Springs, Colo., and Raleigh, N.C.—are outside of it. Participants were located by a telephone survey. Some 432 telephone numbers were systematically selected from the 1974 telephone directory for each of the metropolitan areas. Six randomly selected digits between 1 and 20 added to each of the selected numbers gave a list of 2,592 numbers in each area. The numbers on the list were dialed, and if there was an answer and it was not a business phone, the respondent was asked if the woman of the house would be willing to participate in a table syrup preference study.

In a total of 4,152 households reached, 13 percent of the respondents refused to be interviewed. There were no women in 7 percent of the households, and at 11 percent of the homes, the woman of the house was not available for interviewing. Twenty-two percent of the households had not used table syrup in the 3 months preceding the interview so were not eligible to participate in the study. This left 1,944 potential participants of whom 1,635 said they were willing to take part in the evaluation. Some of the 1,635 moved away or dropped out of the study for other reasons before it was started, leaving 1,509 potential participants.

For paired products testing, each study participant uses two brands, say A and B. There are three possible outcomes: the participant may respond (1) I prefer A to B, (2) I prefer B to A, or (3) I have no preference. For this study, each participant received one syrup at a time, and the order in which the syrups were sent was random. The syrups were referred to as "table syrup" in the cover letter and questionnaires, so the participant did not know the identity of the syrups.

The questionnaire was developed from a discussion that took place during a focus session with eight Vermont housewives, who identified seven characteristics of the test syrups. The questionnaire sent with the first bottle of syrup asked the participant's age, income, size of household, and past use of table syrup. The syrup evaluation section gave directions on how to rate the characteristics of the syrup both before and after use. The participants were asked to comment on their satisfaction with the syrup. The participant received a questionnaire with the second syrup which also included an evaluation section, and the final question asked for a preference rating between the two syrups.

Paired syrup samples were sent through United Parcel Service to 1,509 households and 1,018 questionnaires were returned. Two hundred names were randomly selected from the list of nonrespondents, and 188 of these households were reached by telephone. A short form of the questionnaire was used to interview 96 of the nonrespondents.

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[1] U.S. Food and Drug Commission. 1974. Standards of identity for maple syrup. 29 CFR 30.2, 39 FR 20882 and U.S. Dep. Agric., Agric. Mark. Serv. 1967. U.S. standards for maple syrup. 7 CFR, Part 52, Sec. 52.5961–52.5968.

[2] The use of trade names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

The nonrespondents differed considerably from the respondents in age and geographical distribution, so the data were weighted for location and age. The weighted nonrespondent and the unweighted respondent syrup preference rates were compared. Two of the paired syrup tests were based on too few observations to be analyzed statistically; the other four pairs were analyzed by chi-square tests of homogeneity.

None of the four chi-square tests showed statistical significance. There is no statistical evidence that the two sets of paired syrup test data are different. The data from the respondents should give unbiased estimates of the population parameters. The data from the nonrespondent questionnaires are not included in the data summaries in this paper.

RESULTS

Age, household size, and income

The modal age class of the housewives interviewed in Lansing, Manchester, and Colorado Springs was 25 to 34 years and in Raleigh 35 to 44 years. The number of people in the households averaged 3.38 in Lansing, 3.86 in Manchester, 3.66 in Colorado Springs, and 3.39 in Raleigh. The modal income class of the households was $15,000 to $24,999 for all four cities. However, there were more respondents in the $15,000 and over range in Lansing and Raleigh (46 percent) than there were in Manchester and Colorado Springs (29 percent). More detailed information on respondents can be found in Tables 11 through 13.

It is difficult to generalize about the differences between the survey respondents and the general population. The census unit closest to the areas sampled in our survey is the Urbanized Area, which consists of a central city (or cities) and closely settled surrounding territory.[3] In all cases, differences are small, and are probably the result of differences between the target population of our survey and that of the census.

Analysis of paired syrup preference rates

The preference tests were designed to estimate regional differences in syrup preferences and differences related to past use of syrup.

Table 1 gives the preference rates for each pair of syrups compared. The data suggest that the preference rates depend on whether the person is a pure maple syrup user and whether the person lives inside the syrup-producing region where it is easy to obtain pure maple syrup. The differences between preference rates are small when maple syrups are compared with each other, especially within the maple syrup-producing region. The largest differences are for maple syrups compared to Log Cabin table syrup.

In a paired product test, a "no preference" response may be due to one of the following reasons:

(1) An individual's perception is not sharp enough to detect the difference between products.

(2) The products do not differ in the quality judged.

The smaller the no-preference rate, the sharper the average perception and/or the larger the difference between the products. On the other hand, if the two preference rates and no-preference rate are all close to one-third, it is likely that there is no difference between products. Thus, the outcomes of the tests are random. There are two trends in the no-preference rates in Table 1. The no-preference rates are the highest (and close to one-third) for the U.S. Grade AA to U.S. Grade A test, and lowest for the U.S. Grade B to Log Cabin test.

Preference rates were compared by using chi-square tests of homogeneity to analyze the equality of rates in parallel samples, and tests of goodness-of-fit to analyze whether the outcome of each paired test was due to chance.

Analysis of the preference rates within paired tests. In paired products experiments, it is possible that the preference rates—say π_A and π_B—are equal, or, if the experiments allow ties, that the preference rates equal the rate of ties. The chi-square test of homogeneity (χ^2_h) was used to test the hypothesis

$$\pi_A = \pi_B.$$

The chi-square test of goodness-of-fit (χ^2_g) was used to test the hypothesis

$$\pi_A = \pi_B = 1/3.$$

The results of the two chi-square tests are given

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[3] U.S. Bureau of the Census, Census of Population: 1970, Vol. 1, Characteristics of the population; Part 7, Colorado; Part 24, Michigan; Part 31, New Hampshire; Part 35, North Carolina; U.S. Gov. Print. Off., Washington, D. C., 1973.

Table 1.—Percentage of respondents who preferred one syrup in paired syrup tests, or who had no preference

Syrup pair	Sample size	Respondent's preference U.S. Grade AA	U.S. Grade A	U.S. Grade B	Log Cabin	Neither
NONUSERS WITHIN THE SYRUP-PRODUCING REGION						
AA – A	60	40	33			27
AA – B	69	38		45		17
AA – LC	66	23			53	24
A – B	56		29	45		26
A – LC	68		40		43	17
B – LC	66			32	47	21
NONUSERS OUTSIDE THE SYRUP-PRODUCING REGION						
AA – A	82	25	40			35
AA – B	80	39		44		17
AA – LC	68	16			59	25
A – B	73		27	49		24
A – LC	71		15		72	13
B – LC	83			24	66	10
USERS WITHIN THE SYRUP-PRODUCING REGION						
AA – A	24	21	54			25
AA – B	16	38		44		18
AA – LC	27	37			44	19
A – B	26		31	50		19
A – LC	15		33		47	20
B – LC	23			57	30	13
USERS OUTSIDE THE SYRUP-PRODUCING REGION						
AA – A	3	67	33			0
AA – B	3	33		67		0
AA – LC	3	67			33	0
A – B	4		25	75		0
A – LC	7		29		71	0
B – LC	3			0	100	0

Table 2.—Percentage of respondents who preferred one syrup, or who had no preference, within paired syrup tests by chi-square analysis

Syrup pair	Respondent's preference First syrup	Second syrup	None	X_h^{2a}	X_g^{2b}
	- - - - - - - *Percent* - - - - - - -				
NONUSERS WITHIN THE SYRUP-PRODUCING REGION					
AA – A	40	33	27	0.36	1.60
AA – B	38	45	17	0.44	8.43 *
AA – LC	23	53	24	8.00 **	11.55 **
A – B	29	45	26	1.98	3.25
A – LC	40	43	17	0.07	7.62 *
B – LC	32	47	21	1.92	6.64 *
NONUSERS OUTSIDE THE SYRUP-PRODUCING REGION					
AA – A	25	40	35	3.19	3.25
AA – B	39	44	17	0.26	9.32 **
AA – LC	16	59	25	16.49 **	20.68 **
A – B	27	49	24	4.57 *	8.58 *
A – LC	15	72	13	25.81 **	47.43 **
B – LC	24	66	10	16.33 **	43.10 **
USERS WITHIN THE SYRUP-PRODUCING REGION					
AA – A	21	54	25	3.56	4.76
AA – B	38	44	18	0.08	1.62
AA – LC	37	44	19	0.18	2.89
A – B	31	50	19	1.19	3.78
A – LC	33	47	20	0.33	1.60
B – LC	57	30	13	1.80	6.61 *

[a] Homogeneity, given that one of the two syrups is preferred.
[b] Goodness-of-fit, assuming that the preference probabilities are one-third.
*Significant at 5 percent level.
**Significant at 1 percent level.

in Table 2. For any pair of products, if χ_h^2 and χ_g^2 are both not statistically significant (at the 0.05 level), accept the hypothesis $\pi_A = \pi_B = 1/3$. If χ_h^2 is not statistically significant and χ_g^2 is, accept the hypothesis that $\pi_A = \pi_B$ and reject the hypothesis that $\pi_A = \pi_B = 1/3$. The response rates are equal but they are not 1/3. If χ_h^2 and χ_g^2 are both statistically significant, accept the alternative hypothesis $\pi_A \neq \pi_B$.

How do nonusers of maple syrup perceive the different grades of pure maple syrup? In the syrup-producing region, the data suggest there is no difference in preference for the different grades. Outside of the region, there was no difference in preference between the Grade AA to Grade A and Grade AA to Grade B comparisons. But, Grade B was preferred over Grade A, 49 to 27 percent (Table 2).

In the syrup-producing region the only significant difference was in the Grade AA to Log Cabin comparison. Over one-half (53 percent) of the participants preferred Log Cabin and less than one-fourth (23 percent) preferred Grade AA syrup. Outside the maple region, Log Cabin was preferred to each of the grades of pure maple syrup, on the average of 66 to 19 percent.

All of the chi-square tests of homogeneity of the preference rate for maple syrup users within the maple syrup-producing region are not statistically significant. The power of the chi-square test was too low to detect significant differences from a sample of this size. The sample size for maple syrup users outside the region is too small for valid chi-square tests, so these data are not included in Tables 2 through 5.

Analysis of preference rates across paired tests. Does the preference rate for a particular syrup depend on the syrups to which it is compared? To answer this question, the homogeneity of the preference rates in each column of Table 1 was tested by chi-square analysis. The results are given in Table 3.

Within the maple syrup-producing region, the preference rates for a given syrup by nonusers are homogeneous; outside of the region, this preference rate depends on the syrups to which it is compared. The power of the chi-square test was too low to detect significant differences among the maple syrup users estimated from a sample of this size.

Analysis of regional differences in syrup preference rates. The best data for comparing regional differences in preference rates is the comparison between nonusers within and outside the maple syrup-producing region. None of the pairs of preference rates among the paired pure maple syrup tests is significant (Table 4). The preference rates between regions for Grade AA to Log Cabin are not significantly different. On the other hand, outside of the region, 72 percent of the participants preferred Log Cabin to Grade A and 66 percent preferred Log Cabin to Grade B compared to 43 and 47 percent within the region.

There is a considerable difference between the respondents who have used pure maple syrup in the year preceding the study. Within the syrup-

Table 3.—Percentage of respondents who preferred one syrup in across paired tests by chi- square analysis of homogeneity

Response	Preference			χ_h^2
	First syrup	Second syrup	Third syrup	
	- - - - - *Percent* - - - - -			
NONUSERS WITHIN THE SYRUP-PRODUCING REGION				
Prefers AA to A,B,LC	40	38	23	5.13
Prefers A to AA,B,LC	33	29	40	1.72
Prefers B to AA,A,LC	45	45	32	3.03
Prefers LC to AA,A,B	53	43	47	1.45
NONUSERS OUTSIDE THE SYRUP-PRODUCING REGION				
Prefers AA to A,B,LC	25	39	16	9.63 **
Prefers A to AA,B,LC	40	27	15	11.53 **
Prefers B to AA,A,LC	44	49	24	11.80 **
Prefers LC to AA,A,B,	59	72	66	15.36 **
USERS WITHIN THE SYRUP-PRODUCING REGION				
Prefers AA to A,B,LC	21	38	37	1.93
Prefers A to AA,B,LC	54	31	33	3.20
Prefers B to AA,A,LC	44	50	57	0.62
Prefers LC to AA,A,B	44	47	30	1.38

** Significant at 1 percent level.

Table 4.—Percentage of nonusers of maple syrup within and outside the syrup-producing region who preferred one syrup by chi-square analysis of homogeneity

Preference	Within the region	Outside the region	X_h^2
	- - - - - - - - - Percent	- - - - - - -	
AA to A	40	25	3.32
A to AA	33	40	0.71
AA to B	38	39	0.02
B to AA	45	44	0.02
AA to LC	23	16	0.92
LC to AA	53	59	0.46
A to B	29	27	0.02
B to A	45	49	0.28
A to LC	40	15	10.25 **
LC to A	43	72	12.11 **
B to LC	32	24	1.10
LC to B	47	66	5.61 *

* Significant at 5 percent level.
** Significant at 1 percent level.

Table 5.—Percentage of maple syrup users and nonusers within the syrup-producing region who preferred one syrup by chi-square analysis of homogeneity

Preference	Users	Nonusers	X_h^2
	- - - - - - - - - Percent	- - - - - - -	
AA to A	21	40	2.78
A to AA	54	33	3.12
AA to B	38	38	0.00
B to A	44	45	0.01
AA to LC	37	23	2.00
LC to AA	44	53	0.56
A to B	31	29	0.04
B to A	50	45	0.20
A to LC	33	40	0.21
LC to A	47	43	0.08
B to LC	57	32	4.41 *
LC to B	30	47	1.91

* Significant at 5 percent level.

producing region, 25 percent of the respondents were users compared to only 5 percent outside of the region.

Analysis of preference rates for pure maple syrup users and nonusers. Within the syrup-producing region, preference rates can be compared with past use of syrup (Table 5). The chi-square test indicates that the only significant difference was maple syrup users preferred Grade B syrup to Log Cabin at a preference rate of 57 percent compared to 32 percent for nonusers.

Product perception index

When pure maple syrup is packed in clear glass bottles, the difference in color between the grades of syrup is noticeable. Commercial table syrups are usually dark amber, like Grade B syrup. The lighter colored grades of maple syrup may look thin or diluted to consumers unfamiliar with pure maple syrup. This may be a barrier to sales of the lighter grades outside the syrup-producing region.

An attempt was made to measure the difference between expectation and experience. Expectation, measured before use, was based on the syrup's appearance in the bottle. Seven bipolar word pairs that described table syrup were rated on a 5-point scale by respondents before and after syrup use. The scale was arranged so that the more desirable property was number 1 and the least desirable, number 5. For example, under flavor, it is desirable for a maple-flavored table syrup to have a maplelike flavor, therefore, "maplelike" was number 1 and "not maplelike" was number 5.

An index of product perception is the average of the perception scores. "No opinion" responses for as many as two of the seven items were accepted and the index calculated on the items scaled. The seven items were: consistency (1) heavy to light; flavor (2) full-bodied to delicate, (3) very sweet to not sweet, (4) not honeylike to honeylike, (5) maplelike to not maplelike; aroma (6) strong to weak; and texture (7) smooth to grainy. The closer the calculated index was to 1, the higher the syrup was rated.

The index was calculated by syrup, before and after use. Mean indexes and simple correlation coefficients were calculated between the before-use and after-use indexes (Table 6). The correlations are positive and highly significant.

The differences between the means are statistically significant for all of the pure maple syrups but not for the Log Cabin syrup. For all the pure maple syrups, the change in the perception index was upward, indicating a less favorable impression of the syrup after using it.

There is a trend in syrup rankings. Based on the perception index before syrup use, Grade B ranked highest, followed by Log Cabin, Grade A, and Grade AA. Based on the index after syrup use, which is the most important index, Grade B and Log Cabin ranked equally high, followed by Grade A and Grade AA.

Profiles of the mean perception scores before and after syrup use are shown in Figure 1. The items that had the largest between-to-within variance ratios were pouring consistency; two items under flavor—full-bodied to delicate, maplelike to not maplelike; and aroma.

Respondents were also given the opportunity to evaluate the color of the syrups. Table 7 shows the percentage of respondents, by syrups and regions, who disliked the syrup color. The only concensus among those few who disliked a color was that Grade AA was too light. For the other syrups, the respondents were about equally divided as to whether the product was too light or too dark.

Other syrup characteristics

Pure maple syrup cannot be modified by adding different kinds of syrup, coloring agents, and flavor enhancers to offset changes in ingredient prices or consumer preferences. However, information about desirable and undesirable characteristics of pure maple syrup can be used in marketing the different grades.

Respondents also evaluated pouring consistency, aroma, flavor, and aftertaste. Table 8 shows the percentage of respondents who expressed dislike for one or more of these syrup characteristics.

Dissatisfaction with pouring consistency decreases with darker syrups and correlates with actual density of the syrups tested. Although all pure maple syrups, in theory, have the same density, variation inevitably occurs between batches. The densities of the syrups in this study were Grade AA, 65.4 percent solids; Grade A, 66.0 percent; and Grade B, 67.6 percent. Log Cabin syrup, which is about the same density as pure maple, appears thicker because it contains corn syrup which is more viscous. Although these differences seem minor, they may have been perceptible to the respondents. More than 90 percent of the respondents who disliked the consistency indicated that the syrup was too thin.

The respondents' dissatisfaction with aroma is relatively constant among syrups and between regions (Table 8). Pure maple syrup has a faint aroma when heated. More than two thirds of the respondents complained that the aroma was weak or not present at all.

Although maple flavor is unique, it varies with grade. In the syrup-producing region, the percentage of respondents who disliked the flavor of pure maple syrup is about 14 percent for all three grades (Table 8). Outside of the region, the percentage of those who disliked the flavor is about 22 percent. Considerably fewer respondents (7 percent) disliked the flavor of Log Cabin syrup. This may be the result of Log Cabin's widespread use and the consumer acceptance testing that is done before changing it.

Table 9 gives the percentage of respondents who gave certain reasons for disliking the flavor of each syrup. Regional responses were combined because the differences were small. "Too weak" was the most frequently given reason for disliking the flavor of a syrup, especially for Grade AA.

About 22 percent of the respondents disliked the aftertaste of Grade A and B syrups. Their rea-

Table 6.—Perception index for syrups before and after use

Syrup	Perception index[a]		Correlation coefficient Before & after use (r)	Sample size
	Before use	After use		
U.S. Grade AA maple syrup	2.71 (.03)[b]	2.84* (.03)	0.48	348
U.S. Grade A maple syrup	2.57 (.03)	2.71* (.03)	0.49	323
U.S. Grade B maple syrup	2.33 (.03)	2.41* (.03)	0.44	369
Log Cabin table syrup	2.44 (.03)	2.44 (.03)	0.50	353

[a] Average of perception scores.
[b] Standard error.
* Difference between before and after use significant at the 5 percent level.

Table 7.—Percentage of respondents who disliked syrup color, and total number of respondents

Syrup	Respondents			
	Within the region		Outside the region	
	%	N	%	N
U.S. Grade AA	5.4	276	3.0	234
U.S. Grade A	1.5	262	3.4	233
U.S. Grade B	1.9	269	2.0	250
Log Cabin	2.2	273	0.4	239

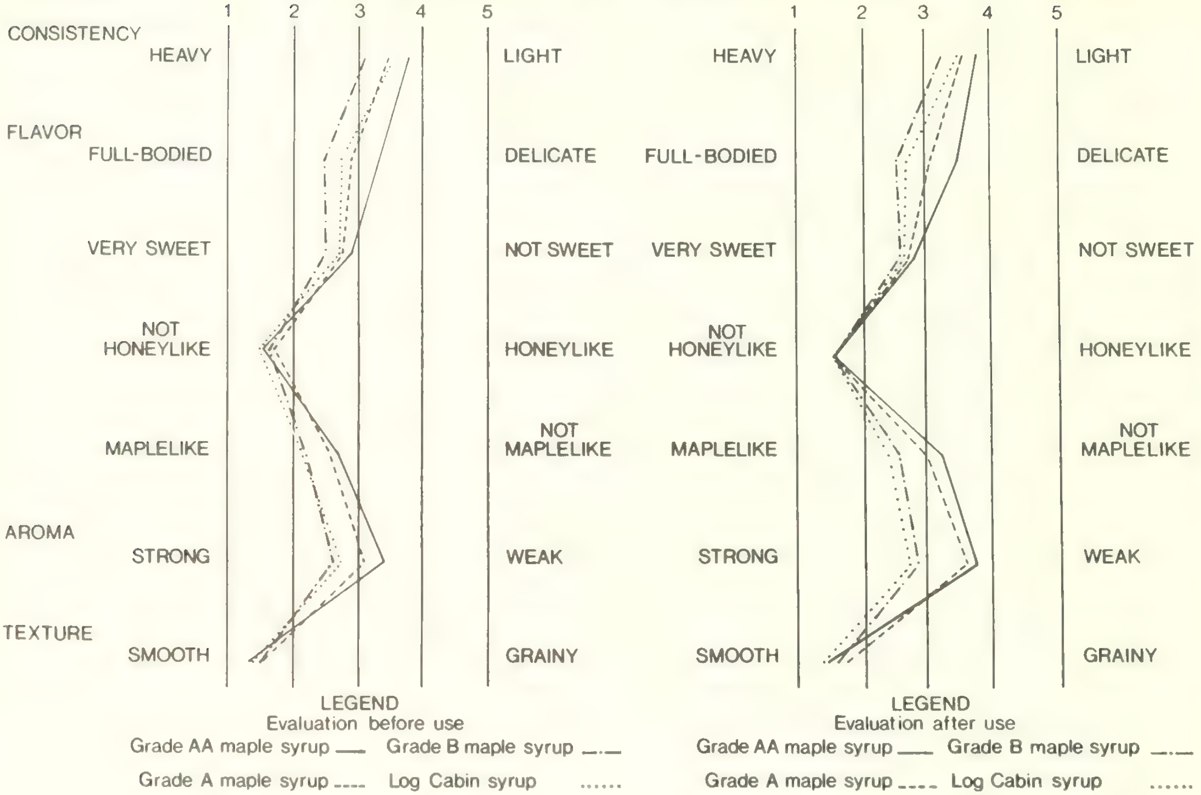
Table 8.—Percentage of respondents who disliked syrup characteristics (and total number of respondents) within and outside the maple syrup-producing region

Syrup	Characteristics							
	Pouring consistency		Aroma		Flavor		Aftertaste	
	Within region	Outside region	Within region	Outside region	Within region	Outside region	Within region	Outside region
U.S. Grade AA	18(276)	19(234)	12(276)	13(234)	16(276)	17(234)	15(276)	16(234)
U.S. Grade A	12(262)	16(233)	8(262)	12(233)	13(262)	27(233)	17(262)	23(233)
U.S. Grade B	8(269)	10(250)	7(269)	10(250)	14(269)	24(250)	21(269)	25(250)
Log Cabin	10(273)	6(239)	6(273)	3(239)	8(273)	6(239)	11(273)	8(239)

Table 9.—Percentage of respondents who gave reasons for disliking the flavor of the syrups, and total number of respondents

Syrup	Flavor					
	Too strong	Too weak	Too sweet	Not maplelike	Other	N
U.S. Grade AA	6	63	14	5	11	98
U.S. Grade A	9	48	22	10	10	98
U.S. Grade B	18	34	24	15	8	91
Log Cabin	7	34	31	15	13	61

Figure 1.—Evaluation of syrups before and after use.



sons are given in Table 10. "Too bitter" was the most frequent reason for Grade A and B syrups. The most frequent description of the aftertaste of Grade AA and Log Cabin syrups was "too sweet."

DISCUSSION

This study shows that there are differences in taste preferences for pure maple syrup and Log Cabin syrup between respondents living in two cities in the syrup-producing region and those in two cities far from this region. Although there are many regional differences that could account for this, it seems likely that the greater chance for use of pure maple syrup in the syrup-producing region is a major factor. This supports the hypothesis that habit plays a key role in food preference.[4] Pure maple syrup is more of a staple in the region of maple syrup production.

Preference rates for pure maple syrup versus Log Cabin syrup were about the same for maple syrup users and nonusers in the syrup region. Preference rates for different grades of maple syrup appear to be at variance with the grading standards. The standards place a premium on lightness of color and delicacy of flavor, but the survey participants either did not recognize the difference among grades or preferred a darker color and more robust flavor.

The largest difference in syrup preference was in the cities outside the syrup-producing region, where the preference for Log Cabin syrup averaged 66 percent. Habit is a likely explanation of this. Log Cabin syrup is the most widely used table syrup in the four cities, and especially in Colorado Springs and Raleigh (Tables 14 and 15).

The inability to distinguish the flavors of different grades of pure maple syrup may be caused by the number of flavors the average consumer encounters in the table syrups generally used. In this survey, and in an earlier investigation of pure maple syrup users, several different brands and types of table syrup were in the participant's home at the time of the study. The participants in this survey who lived outside the region judged the difference between grades of pure maple syrup to be

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[4] Todhunter, E. N. 1973. Food habits, food faddism and nutrition. World Rev. Nutr. Diet. 16:286–317.

Table 10.—Percentage of respondents who gave reasons for disliking aftertaste of the syrups, and total number of respondents

Syrup	Aftertaste				
	Too bitter	Too sweet	Dis-agreeable	Other	N
U.S. Grade AA	32	38	20	11	56
U.S. Grade A	40	23	15	22	81
U.S. Grade B	39	22	20	20	82
Log Cabin	25	30	20	25	40

much less than the difference between pure maple syrup and Log Cabin syrup.

The implications for marketing are clear. To increase the use of pure maple syrup, a promotion campaign will be required to acquaint consumers with maple syrup characteristics, particularly taste. The disparity between grade and price and consumer preference should be resolved. The sale of a product is not helped by a Grade B designation. The implication to the consumer, who knows nothing about the product, is that it must be inferior to Grade A.

It would seem appropriate to change from grades to a more descriptive evaluation, such as light, medium, and dark amber. The identifying standard allows the use of such descriptive terms along with the grade designations. However, the use of the descriptive terms within one level of product quality would seem to be a preferred approach.[5] The survey results indicate that two descriptive classes of maple syrup, such as light and dark, might be even more appropriate.

Before marketing strategies can be recommended, the effects of syrup price and identification must be assessed. This survey shows that more people preferred the taste of pure maple syrup than are using it. However, sales of maple syrup are determined in the market, where the consumer can choose among brands of table syrups and pure maple syrup.

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[5] Such a proposal is before the industry now [Proposed: (7 CFR Part 52) Fed. Reg. Vol. 42, No. 82, 28 Apr. 77].

APPENDIX

Table 11.—Percentage of participating housewives in each age class in the four cities

Age class (years)	City			
	Lansing	Manchester	Colorado Springs	Raleigh
Less than 20	1.5	2.3	4.0	—
20-24	8.8	8.7	9.9	8.2
25-34	25.4	29.2	25.8	20.5
35-44	19.6	19.7	21.8	22.8
45-54	20.8	20.5	19.0	22.8
55-64	13.8	11.7	11.1	16.4
More than 64	10.0	8.0	8.3	9.1
Total number of respondents	260	264	252	219

Table 12.—Distribution of household size in the four cities (in percent)

Number in household	City			
	Lansing	Manchester	Colorado Springs	Raleigh
1	6.9	4.5	6.0	5.1
2	29.0	22.4	26.0	28.1
3	20.5	19.0	15.6	22.6
4	20.5	22.8	28.4	22.1
5	14.7	15.3	14.0	14.8
6	5.0	8.6	5.6	5.1
7 or more	3.5	7.5	4.4	2.3
Total number of respondents	259	268	250	217

Table 13.—Distribution of households in the four cities by family income class (in percent)

Income class	City			
	Lansing	Manchester	Colorado Springs	Raleigh
Under $5,000	7.9	7.4	6.6	8.0
$ 5,000-$ 7,999	9.1	15.3	13.6	7.5
$ 8,000-$ 9,999	10.3	8.7	13.2	7.5
$10,000-$11,999	14.3	21.5	14.5	11.9
$12,000-$14,999	17.1	21.5	20.7	13.4
$15,000-$24,999	31.3	22.3	26.0	37.3
$25,000 & over	9.9	3.3	5.4	14.4
Total number of respondents	252	242	242	201

Table 14.—Table syrups in households at the time of survey and purchased more than once in the 12 months preceding survey within the maple syrup-producing region (in percent)

Syrup	In household	Purchased more than once
Log Cabin	23.0	28.0
Vermont Maid	16.6	21.6
Pure Maple	11.2	6.4
Aunt Jemima	9.8	11.4
Mrs. Butterworth's	9.1	10.5
Karo Light	8.3	4.5
Karo Dark	3.2	1.2
Food Club	3.1	2.4
Staley	2.6	2.9
Smuckers Blueberry	1.1	1.0
All others	12.0	10.2
Total mentions	1,936	842

Table 15.—Table syrups in households at the time of survey and purchased more than once in the 12 months preceding survey outside the maple syrup-producing region (in percent)

Syrup	In household	Purchased more than once
Log Cabin	27.5	35.1
Karo Light	15.3	14.2
Mrs. Butterworth's	7.7	7.0
Staley	5.7	5.2
Karo Dark	5.4	3.9
Aunt Jemima	4.5	3.9
Golden Griddle	4.2	3.7
Ann Page	2.6	1.9
Bar-None	2.3	3.1
Country Kitchen	1.9	1.7
Pure Maple	1.9	1.2
All others	22.0	19.2
Total mentions	1,910	970

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FERTILIZATION INCREASES GROWTH OF SAWLOG-SIZE YELLOW-POPLAR AND RED OAK IN WEST VIRGINIA

by N. I. Lamson

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NORTHEASTERN FOREST EXPERIMENT STATION
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Abstract

Sawlog-size even-aged hardwood stands in north-central West Virginia were fertilized with N, P, and K, singly and in combinations. Applications of N alone increased the annual basal area growth of yellow-poplar more than that of red oak during the first 7 years after fertilization, whereas P alone increased the annual basal area growth of red oak more than that of yellow-poplar. NP did not stimulate the growth of yellow-poplar more than did N alone and did not increase the growth of red oak more than did P alone. The 7-year cumulative basal area growth of yellow poplar was increased 34 percent by N, while that of red oak was increased 20 percent by P. NPK usually increased the growth of both species over that of the control trees, but usually not more than that of N or P, singly or combined. N fertilization could increase the 7-year volume growth of pure stands of sawlog-size yellow-poplar by about 30 percent in this region.

INTRODUCTION

Forest fertilization has been relatively common in this country since the early 1950s, and studies have been made to determine fertilizer rates for optimum tree growth. However, recent summaries of such studies in the United States and Canada point to the need for a greater understanding of the nature and distribution of nutrient deficiencies in the forest landscape (Krause 1973, Safford 1973, Auchmoody and Filip 1973, Leaf 1974).

Of equal importance are the economic aspects and effects on water quality of forest fertilization. Economics will ultimately dictate the extent to which forest fertilization will be used as a management tool, and water quality effects may further influence application methods and prescription criteria.

In this paper, I discuss the growth of sawlog-size yellow-poplar and red oak following N, P, and K fertilization. The trees were growing on Gilpin or Calvin soils in north-central West Virginia.

METHODS

The study was established in Tucker and Randolph Counties of north-central West Virginia. This area of rugged mountainous terrain receives about 140 cm of precipitation annually and has a frost-free period of about 150 days. Eleven independent study areas located in fully-stocked, even-aged hardwood stands 50 to 70 years old were used in this study. Soils in the areas are well- drained silt loams, about 90 cm deep to sandstone and shale bedrock, belonging to either the Gilpin or Calvin series (Typic Hapludults and Typic Dystrochrepts). The red oak site index for the areas ranged between 20 and 23 m.

Each area contained five plots ranging from .08 to .13 ha. The minimum distance between plots was 15 m, but this distance usually exceeded 46 m. Each plot contained 3 to 10 domimant or codominant yellow-poplar (*Liriodendron tulipifera* L.) or red oak (*Quercus rubra* L.) trees from 30 to 41 cm in diameter at 1.37 m (dbh). In all, 199 yellow-poplar and 78 red oak trees were used to measure the response to fertilization.

Each study tree was equipped with an aluminum band dendrometer at a height of 1.37 m; the diameter was recorded to the nearest .25 mm. Diameter measurements were taken each October for 5 years and again 7 years after fertilization (Fig. 1).

Four fertilizer treatments and the control were evaluated:

C = no fertilizer
P = 224 kg P_2O_5/ha
N = 336 kg N/ha
NP = 336 kg N + 224 kg P_2O_5/ha
NPK = 336 kg N + 224 kg P_2O_5 + 112 kg K_2O/ha

The fertilizers used were urea, triple superphosphate, and muriate of potash. Fertilizers were broadcast in early May 1970. Nitrogen and phosphorus were reapplied at the same rate in May 1971 to ensure their availability during the second growing season.

The basal area growth of individual trees was used to evaluate the treatments. The initial basal

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140 cm = 55 in
90 cm = 2.95 ft
20 m = 65 ft
23 m = 75 ft

.08 ha = ⅕ acre
.13 ha = ⅓ acre
15.2 m = 50 ft
45.7 m = 150 ft
30.5 cm = 12 in
40.6 cm = 16 in
1.37 m = 4.5 ft
.254 mm = .01 in
224 kg/ha = 200 lb/acre
336 kg/ha = 300 lb/acre
112 kg/ha = 100 lb/acre

Figure 1.—Sawlog-size yellow-poplar equipped with dendrometers. Fertilization increased the annual basal area growth.

area was used as a covariate to compensate for growth differences related to tree size. Basal area growth data were analyzed as a randomized complete block design with a control and four treatments in each block. There were seven yellow-poplar blocks and four red oak. Paired comparisons among the treatments were tested for significance at the .05 level using a Scheffé test.

RESULTS

The results of the first 3 years after fertilization were reported by Auchmoody and Smith (1977). In this paper, the growth patterns 4 to 7 years after fertilization are discussed, and the 7-year growth response is summarized.

Basal area growth

Yellow-poplar.—No statistically significant differences in the average annual basal area growth were found among the treatments for the 4th through 7th years after fertilization (Table 1). However, the average annual basal area growth of the N-fertilized trees was 28 percent more than that of the control trees, and the NP-fertilized trees, 23 percent more than that of the controls (Fig. 2).

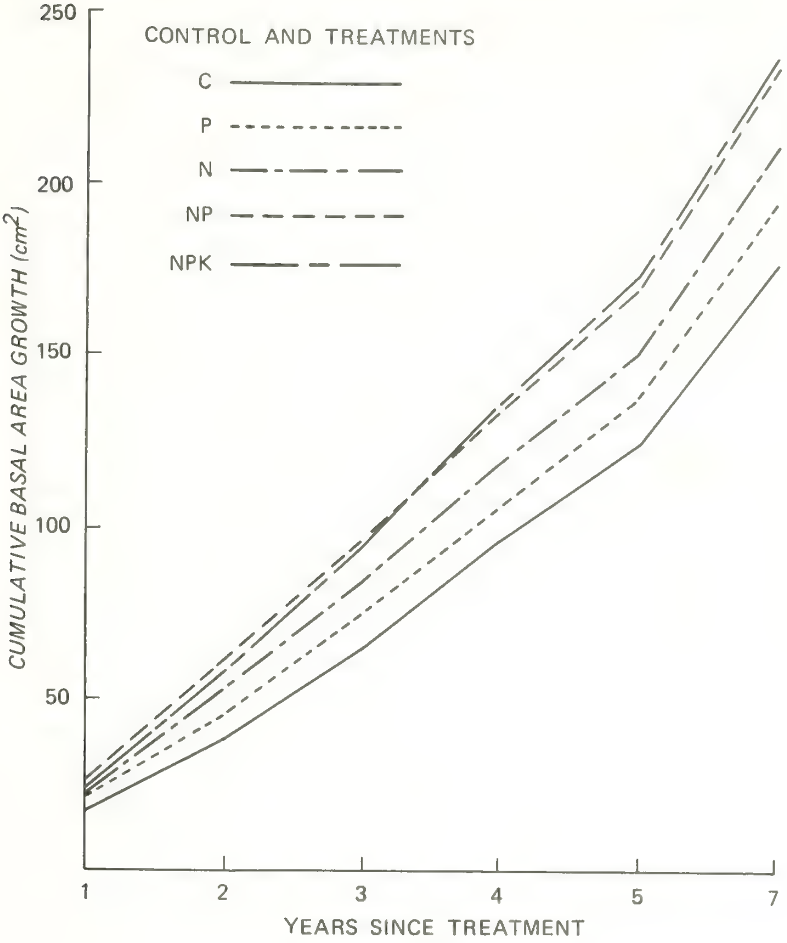
The fact that P, alone or in combination with N, had very little effect on the average annual basal area growth over that of the control trees or those fertilized by N shows that P is not limiting for yellow-poplar growth on these soils. The in-

Table 1.—Average basal area growth of yellow-poplar and red oak trees and percentage of increase after fertilization compared to unfertilized trees

Control and treatment	Yellow-poplar		Red oak	
	cm^2	%	cm^2	%
		1ST YEAR		
C	16.9a	—	19.5a	—
P	20.4a	21	26.7b	37
N	23.2a	37	24.3a	25
NP	25.7a	52	25.6b	31
NPK	21.2a	25	22.7a	16
		2ND YEAR		
C	22.3a	—	31.8a	—
P	25.7a	15	38.4a	21
N	34.9b	56	41.2a	30
NP	34.9b	56	43.4a	36
NPK	31.4a	41	39.4a	24
		3RD YEAR		
C	25.6a	—	36.8a	—
P	28.1a	10	43.1a	17
N	36.2b	41	44.8a	22
NP	35.2b	38	48.2a	31
NPK	31.1a	21	45.3a	23
		4TH YEAR		
C	32.33a	—	43.29a	—
P	31.96a	−1	47.75a	10
N	40.69a	26	45.80a	6
NP	38.18a	18	46.73a	8
NPK	35.39a	9	45.24a	5
		5TH YEAR		
C	27.78a	—	40.59a	—
P	32.89a	18	49.89a	23
N	37.72a	36	43.57a	7
NP	35.86a	29	43.85a	8
NPK	31.40a	13	39.02a	−4
		7TH YEAR		
C	26.85a	—	40.50a	—
P	27.78a	3	46.64a	15
N	32.89a	22	40.50a	0
NP	33.07a	23	45.15a	12
NPK	29.91a	11	35.58a	−12
		1 TO 7 YEARS		
C	178.61a	—	252.98a	—
P	194.61a	9	299.12a	18
N	238.49a	34	280.67a	11
NP	235.98a	32	298.08a	18
NPK	210.31a	18	262.82a	4

Values in columns followed by the same letter are not significantly different at the 0.05 level.

Figure 2.—Cumulative basal area growth of yellow-poplar.



creased growth of the NP-fertilized trees was apparently due to the N.

The total basal area growth for the 7-year period indicated a response to N and NP fertilization, but no statistically significant differences were found among treatments. N and NP fertilization increased the total basal area growth for the 7-year period by 34 and 32 percent.

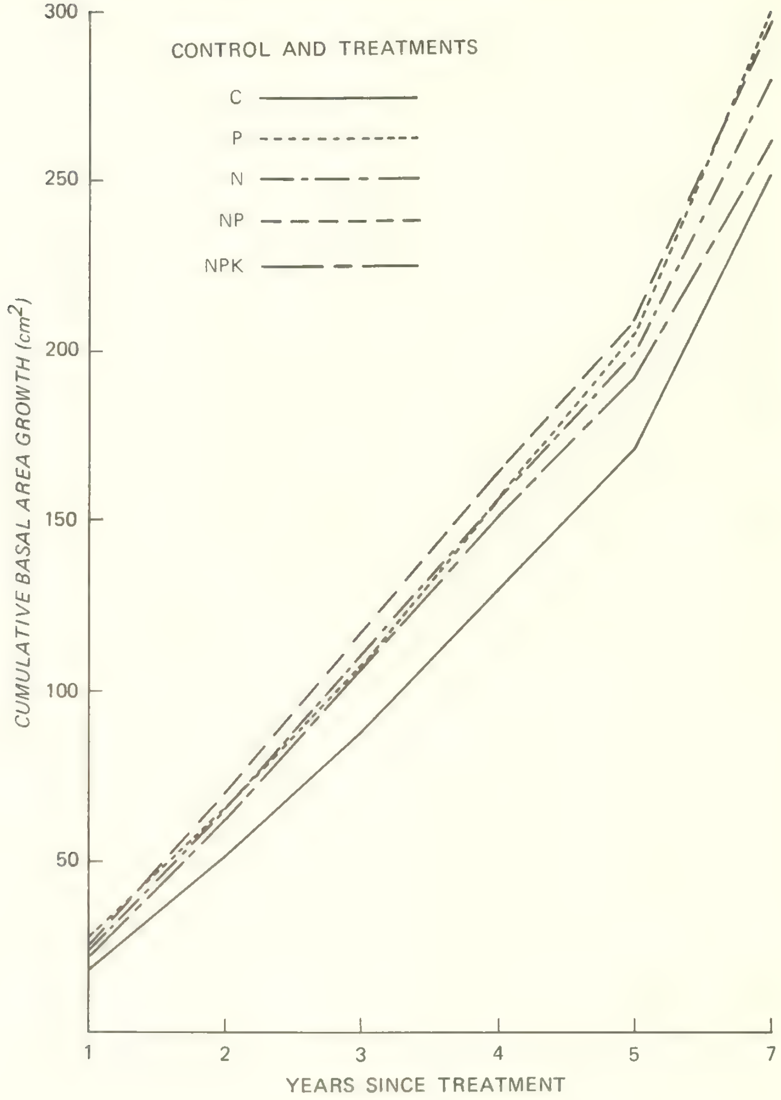
Annual basal area growth of NPK-fertilized trees averaged about 11 percent more than that of the control trees during the 4-year period. The 7-year periodic basal area growth following NPK treatment was only 18 percent more than that of the control. Similar trends were observed by Auchmoody and Smith (1977) during the first 3 years following treatment (Table 1). The reasons for NPK-fertilized trees growing less than N- or NP-fertilized trees are not clear.

Red oak. Red oak was less responsive to treatment than yellow-poplar. Although no statistically significant differences were found among the treatments for the 4th through 7th years, P increased the annual basal area growth an average of 16 percent over that of the control trees; NP, 9 percent; and N, 4 percent (Table 1). The growth response to fertilization was P > NP > N > C > NPK for the 4th through 7th years after treatment. P fertilization continued to increase red oak basal area growth 7 years after treatment (Fig. 3). It appears that most of the response to N fertilization was in the first 3 years

The P, N, and NP treatments increased the 7-year basal area growth 18, 11, and 18 percent. Although no statistically significant differences were found among the treatments, the response to P is evident.

The NPK treatment usually resulted in less average annual basal area growth than did the P, N,

Figure 3.—Cumulative basal area growth of red oak.



and NP. In fact, during the 4th through 7th years, the NPK treatment resulted in about 4 percent less growth than that of the control trees.

DISCUSSION

The lack of statistically significant differences among the treatments was probably due to the high variation both within and among blocks. A less conservative test than the Scheffé might have declared more means significantly different.

The relative basal area growth of yellow-poplar in response to N fertilization can be seen in Figure 4. This growth was greatest 2 years after treatment, then it generally declined. The fact that the growth of the P-fertilized trees was only slightly greater than that of the controls shows that the increased growth following NP fertilization probably resulted from the N.

The relative basal area growth of the P-fertilized red oak was about the same as that of the N- and NP-fertilized trees during the first 3 years after treatment, and greater during the 4th through 7th years after treatment (Fig. 5).

This study did not include an analysis of Gilpin and Calvin soils, but our data on diameter growth

Figure 4.—Relative basal area growth of yellow-poplar.

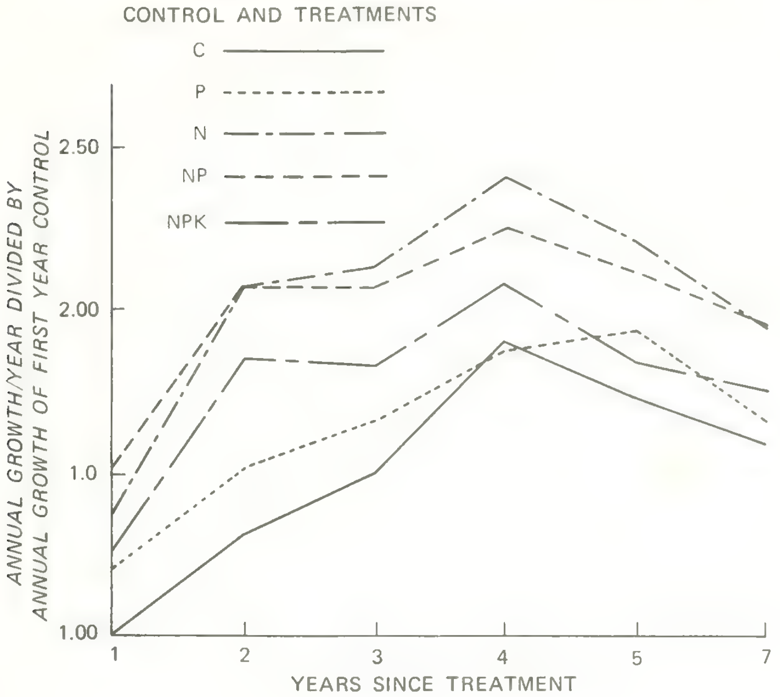
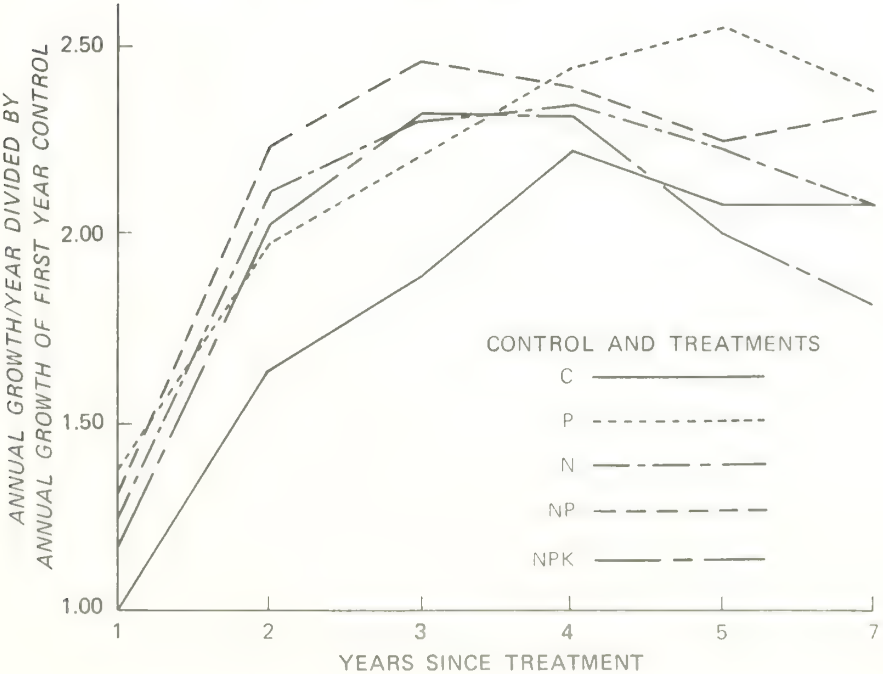


Figure 5.—Relative basal area growth of red oak.



following fertilization suggest that these soils are deficient in nitrogen for the maximum growth of yellow-poplar, and in phosphorus for red oak.

Although nearly pure stands were studied, only the dominant and codominant trees were measured, so data per hectare are lacking. However, nearly all the volume growth in a sawlog-size stand occurs in the dominant and codominant trees. Thus, the observed 34 percent increase in the growth of N-fertilized yellow-poplar would result in at least a 30 percent increase in the volume growth of the stand.

The expected 7-year volume growth for yellow-poplar stands on sites similar to those in this study is 12.25 m^3/ha. Our study indicates that this volume could be increased to 15.92 m^3/ha, or about 30 percent, by the N treatment. The average diameter of the yellow-poplars was 38 cm dbh before fertilization, and normal growth is about 4 annual rings per cm. This growth rate could be increased to about 3 annual rings per cm by N fertilization.

CONCLUSIONS

Following the fertilization specifications set up for this study in West Virginia:

The average annual and the 7-year cumulative basal area growth of N-fertilized yellow-poplar trees was 36 percent more than that of control trees. The N treatment could be expected to increase the 7-year volume growth of sawlog-size yellow-poplar stands by at least 30 percent.

The average annual and cumulative basal area growth of P-fertilized red oak trees was 20 and 18 percent more than that of the control trees.

The application of N increased the basal area growth of yellow-poplar more than that of red oak, while the application of P increased the basal area growth of red oak, more than that of yellow-poplar.

The application of NP did not increase the growth of yellow-poplar more than N alone, and did not increase the growth of red oak more than P alone.

Fertilization with NPK generally increased the growth of both species—though not substantially—over that of the control trees, but usually not more than that of N or P applied singly or combined.

38.1 cm = 15 in
4 rings/cm = 10 rings/in
3 rings/cm = 7.8 rings/in
12.25 m^3/ha = 2,100 fbm/acre
15.92 m^3/ha = 2,730 fbm/acre

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- Warren, Pennsylvania.

By William J. Gabriel

GENETIC VARIATION IN SEED AND FRUIT CHARACTERS IN SUGAR MAPLE

FOREST SERVICE RESEARCH PAPER NE-404
1978
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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370 REED ROAD, BROOMALL, PA 19008

Abstract

A study of the seeds and fruits of sugar maples from 32 provenances has shown that: (1) dry weight of seed and percentage of filled fruit varied genetically among and within provenances; (2) dry weight of seed and latitude of provenance are positively correlated; provenances from higher latitudes and colder temperatures exhibited higher weights; (3) the percentage of filled fruit was not significantly related to dry weight of seed and was negatively correlated with latitude; (4) dry weight of seed exhibited a complex pattern of genetic variation; in the northeast the variation was ecotypic with a strong suggestion of a cline within ecotype; in the remainder of the species' range the variation appeared clinal in nature.

The Author

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INTRODUCTION

SUGAR MAPLE (*Acer saccharum* Marsh.) grows from Minnesota through eastern Canada and south into Tennessee and Missouri. The different environments within this wide range exert selection pressures which the species must adapt to if it is to survive. Consequently, the potential for genetic variability in sugar maple is high.

In support of our program to improve sugar maple, samples of seed from throughout the species range were collected for a study of the nature and pattern of genetic variability. Currently, the study is in its early stage of development with outplantings established in Vermont, New York, West Virginia, and Michigan.

Before the outplantings were established, the differences in the dry weight of seed and the percent of filled fruit of the samples were examined. This paper reports on the variations observed within and among provenances.

MATERIALS AND METHODS

Seeds and fruits were collected from eight trees within each of 32 provenances (Table 1). Freedom from damage caused by insects and disease was the criterion for the selection of mother trees. All collections were kept separate, by tree within provenance, during the experiment.

The average values derived from the percentage of filled fruit and dry weight of seed were based on

Table 1.—Location and elevation of provenances of *Acer saccharum*

Seed lot	Town	District or county	State or province	Latitude north	Longitude west	Elevation
						Ft
3	Hinton	Caddo	OK	35°30′	97°45′	1,100
7	Cumberland	Harlan	KY	36°55′	82°57′	3,600
8	Carbondale	Jackson	IL	37°40′	89°10′	425
9	Parsons	Tucker	WV	39°02′	79°40′	2,400
10	Hoosier Natl. For.	Monroe and	IN	38°56′	86°31′	600
		Lawrence	IN	38°56′	86°31′	600
11	Greendale	Hocking	OH	39°34′	82°17′	700
	Maxville	Perry	OH	39°34′	82°17′	840
12	Ligonier	Dist. #4	PA	40°10′	79°10′	1,500
13	Alliance	Columbiana	OH	40°57′	81°10′	1,120
14	Irvine and		PA	41°50′	79°16′	1,200
	Warren	Warren	PA	41°50′	79°07′	1,300
15	East Lansing	Ingham	MI	42°45′	84°30′	600
16	Stamford	Delaware	NY	42°27′	74°38′	2,200
17	Lanesboro	Berkshire	MA	42°32′	73°15′	1,500
18	Plainfield	Sullivan	NH	43°27′	72°23′	400
	Newport	Sullivan	NH	42°37′	72°23′	400
19	Hancock	Addison	VT	43°55′	72°50′	950
20	Indian River	Lewis	NY	44°00′	75°23′	900
21	Maple	York	ON	43°50′	79°30′	500
22	Grayling	Crawford	MI	44°35′	84°45′	1,300
23	Farmington	Franklin	ME	44°40′	70°07′	560
24	Bradley	Penobscot	ME	44°52′	68°39′	200
25	Argonne Exp. For.	Forest	WI	45°42′	89°02′	
26	Ste. Anne de Bellevue		PQ	45°15′	74°00′	150
27	Killarney	Manitoulin	ON	45°58′	81°31′	600
28	Amasa	Iron	MI	46°15′	88°33′	1,550
29	Quebec City		PQ	46°44′	71°18′	330
30	St. Quentin	Victoria	NB	47°20′	67°38′	1,000
31-A	Pike Bay Exp. For.	Cass	MN	47°15′	94°30′	1,300
33	North Branford	New Haven	CT	41°20′	72°45′	200
34	Mille Lacs	Mille Lacs	MN	46°03′	93°40′	1,300
35	Fairfield	Franklin	VT	44°48′	72°57′	600
36	Underhill Center	Chittenden	VT	44°28′	72°56′	750
37	Wallingford	Rutland	VT	43°27′	72°54′	1,575
38	Bennington	Bennington	VT	42°57′	73°10′	1,000

three samples taken from each seed lot. For the filled fruit determinations, the number of fruits that were opened to obtain 15 seeds was recorded for each sample. Dry weights were based on 10-seed samples that were oven-dried at 40°C and weighed on an electronic balance.

Since a portion of the seed is sacrificed when dry weights are determined, the quantities of seed collected in provenances 3 and 22 (Oklahoma and Michigan) were judged to be too small to be included in the study. Similarly, the mean values for provenances 9, 11, 14, and 28 were based on seed collections from 7, 6, 5, and 7 mother trees. These provenances were not included in the computations because the number of seeds in one or more seed lots was inadequate.

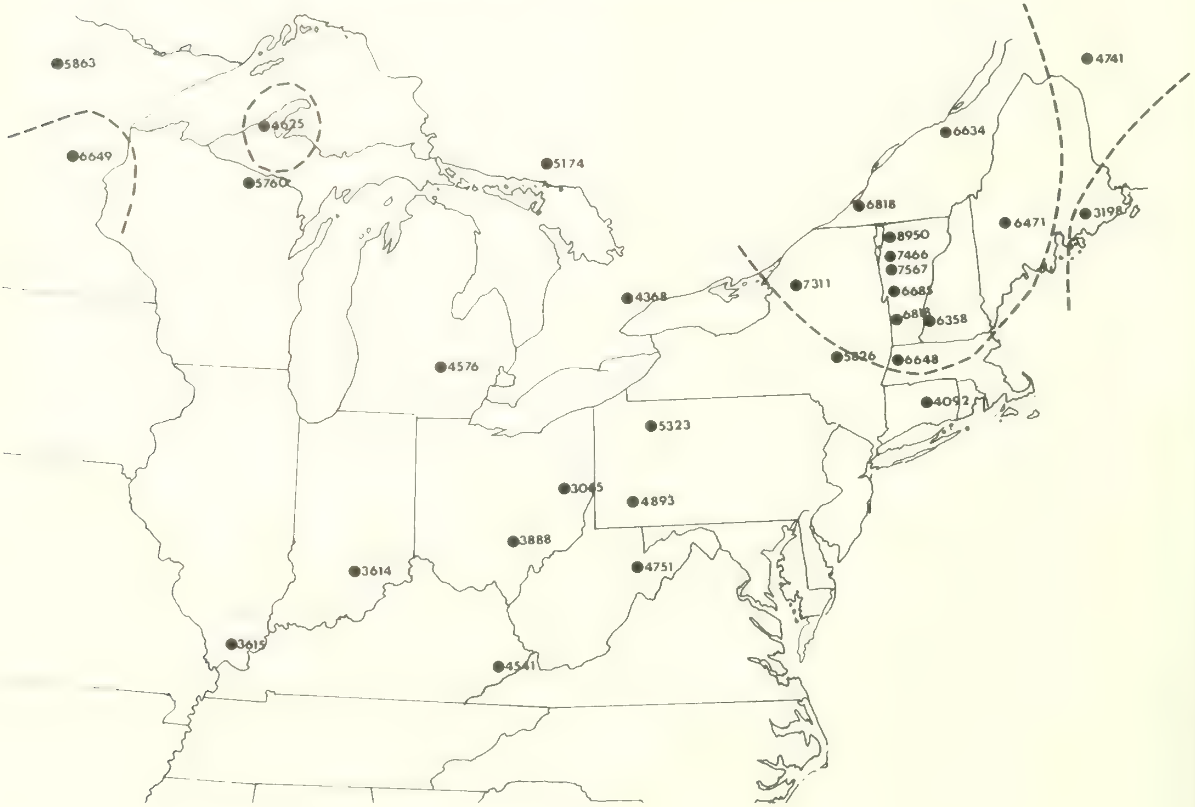
Analysis of variance was used to evaluate the significance of differences among and within provenances. Before the analysis, an angular transformation of the percentage of filled fruit was made, scatter diagrams and maps were drawn, and correlation analyses were run to illustrate the relations of attributes to each other and to the latitude of seed origin.

RESULTS AND DISCUSSION

Dry weight of seed

The dry weight of seed is highly variable in sugar maple. Differences between and within provenances were highly significant. Provenance means (in grams) ranged from 0.8950 g (northern Vermont) to 0.3065 g (southeastern Ohio). The variation within provenance was greatest along the north shore of Georgian Bay, Ontario, where averages varied from 0.8699 g to 0.5258 g. The least variation was found in Quebec, where averages ranged from 0.7582 g to 0.57705 g. Among all 233 seed lots in the study, the highest dry weight average was 1.1152 g (Vermont); the lowest was 0.1995 g (Maine).

Figure 1.—Dry weight of seed plotted according to origin (Grayling, Michigan, and Hinton, Oklahoma not shown), with approximate boundary of northeastern ecotype. (Means in grams x 10^{-4}.)



A simple north-south gradient was found in the western and central parts of the study area (Fig. 1). In general, the northern sources had higher dry weights than the southern. Correlation between weight and latitude was significant at the 1 percent level (r = 0.486). The higher weights among the Kentucky and West Virginia origins are irregularities that may be related to the higher elevations of the seed collection sites (Table 1).

Variation in the northeast was characterized by a moderately distinct ecotype (Fig. 1). The average dry weight of seed of provenances in this ecotype exceeded that of the other origins in the study by 42 percent. Boundaries of this ecotype generally followed the Adirondack Mountains on the west, and the Berkshire Mountains on the south. The relatively heavy seed and the insect pollen vectors typical of sugar maple suggest that the mountains could offer an effective barrier to gene exchange between most of the New England region and the remaining part of the species' range.

A more intensive sampling was made within a relatively small area of the ecotype. Seed collections were made in five locations along a north-south transect in Vermont. The average dry weights of seed for each origin and the corresponding average annual minimum temperature for the general area of each seed collection are:

Origin north to south	*Average annual minimum temperature (degrees C)*	*Average dry weight (grams)*
Fairfield	− 47.8	0.8950
Underhill	− 39.1[1]	.7466
Hancock	− 43.2	.7567
Wallingford	− 36.0	.6685
Bennington	− 35.6	.6618

The apparent north-south trend in seed weights strongly suggests a cline within the ecotype. The gradient in minimum temperature is in general agreement with the dry weight gradient. From this, the inference is drawn that higher dry weights of seed associated with higher latitudes are an adaptive response of the species to colder climates. Factors relating heavier seed to survival are beyond the scope of this study. However, in other species, rapid initial growth of seedlings was correlated with seed weight (Adams and Thielges 1976, Gall and Taft 1973); this has not yet been demonstrated in sugar maple.

Percentage of filled fruit

The percentage of filled fruit was relatively uniform over a large part of the area, although differences among and within provenances were statistically significant. But most provenance means were closely grouped about the overall mean of 49.5 percent. The significant difference found in the analysis was attributed to the large variation among a smaller number of provenances in the extreme north and south part of the area.

The percentage of filled fruit was highest among southern origins (Fig. 2), particularly Illinois (63 percent), Kentucky (61 percent), and southeastern Pennsylvania (60 percent). The lowest values were found in the north: two origins from Ontario (33 and 40 percent), Minnesota (42 percent), and Wisconsin (42 percent). No clear indications of ecotypes were found, but the expression of clinal variation seemed stronger in the central and western parts of the study area.

Variation within provenance was highest among seed lots from the northwestern Pennsylvania origin (21 to 83 percent). The least variation was found in the two seed origins from Maine (49 to 51 percent and 50 to 52 percent). Among the 233 seed lots studied, the percentage of filled fruit was highest (90 percent) in northern Vermont and lowest (21 percent) in northwestern Pennsylvania.

A negative relation between the percentage of filled fruit and the latitude of seed origin was found. In the analysis of correlation, the coefficient (r = − 0.484) was significant at the 1 percent level. The percentage of filled fruit was comparatively uniform among provenances in the northeastern dry seed ecotype, averaging only 1.5 percent above the overall study mean.

The percentage of filled fruit was not found to be correlated with dry weight of seed. The low correlation coefficient value of + .0145 was not significant.

The number of species competitive with sugar maple increases from the northern hardwood region, through a broad area of transition, into the central hardwood region (Braun 1950). Thus, the pattern of variation in the percentage of filled fruit suggests an adaptation to increased competition for the more mesophytic sites.

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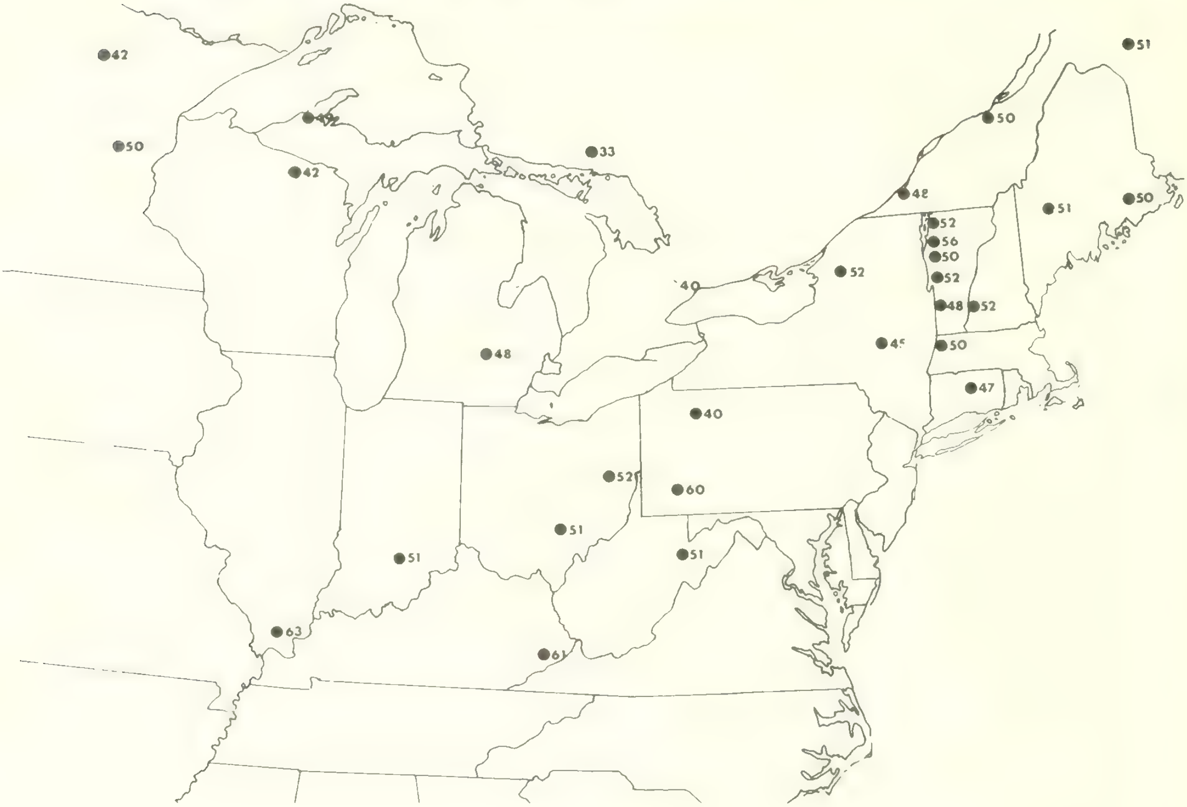
[1] Based on weather data taken at Burlington Airport. Temperatures at Underhill are 5 to 6 degrees colder, according to personal communications with personnel at the Proctor Maple Research Farm at Underhill.

Figure 2.—Percentage of filled fruit plotted according to origin (Grayling, Michigan, and Hinton, Oklahoma not shown).



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Estimating Defoliation of Hardwoods Using Blade-petiole Relations

by Harry T. Valentine

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Abstract

Prediction equations for estimating leaf blade area and dry weight from measurements of petiole thickness were used to estimate defoliation of *Populus tremuloides, Acer rubrum, Quercus rubra,* and *Q. alba.* On one tree of each species, a sample of leaves was artifically browsed in May and harvested in July. The fractions of leaf blade tissue remaining in the samples after treatment in May were compared to the fractions remaining after harvest in July, which were calculated using the blade-petiole relations. Significant differences were found between the fractions for all species except *P. tremuloides.* Late browsing treatments were applied to leaf samples of the same trees in July. Except for the remaining fraction of *Acer rubrum* blade dry weight, all fractions calculated after harvest in August were reasonably close to measured fractions after treatment, although some statistically significant differences were found.

INTRODUCTION

PURPORTED ESTIMATES of defoliation of broadleaved trees by insects are often guesses based on the appearance of leaves. This is due, in part, to the lack of methods for estimating the leaf area or dry weight consumed by the insects, especially when the normal margins of the leaves are destroyed.

Most insects consume tissue from the leaf blade only, leaving the leaf petioles unscathed. Therefore, I examined regression equations that describe dimensional relations between blade dry weight and petiole thickness, and blade area and petiole thickness in oven-dry leaves. I used the regression equations to estimate what the blade dry weights and blade areas in samples of partially browsed leaves would be if the blades were whole. With these estimates, and measurements of the actual blade dry weights and blade areas of those same browsed leaves, I estimated the remaining fractions of the total expected blade dry weight and blade area and their standard errors for each sample.

METHODS

Four tree species—quaking aspen *(Populus tremuloides),* red maple *(Acer rubrum),* red oak *(Quercus rubra),* and white oak *(Q. alba)*—were studied in three locations—Ludlow, Massachusetts; Branford, Connecticut; and Pittstown, New Jersey. Fifty leaves each were collected from three trees of each species in each location on or about June 15, July 15, and August 15, 1976. The leaves were pressed and oven-dried for at least 5 days at 80 C. Then oven-dry weights of the leaf blades were measured to the nearest 0.1 mg. Blade areas were measured with an electronic area meter to the nearest 0.1 cm. Petiole thicknesses were measured with a micrometer to the nearest 0.1 mm. The micrometer had a built-in feature that permitted application of a constant 1.75 lb•ft (2.37 N•m) torque when it was tightened about each petiole. Thus, each petiole was measured under the same pressure.

The petiole measurements of red maple and red and white oak were taken at the petiole-blade junctions, so that each measured thickness was perpendicular to the blade surface. Pressing and oven-drying almost always produced a twist in the petiole near the petiole-blade junction of aspen leaves, and accordingly, their petiole thicknesses were measured just past the twist on the side away from the blade. The measured thickness was the minor axis of the roughly elliptical petiole cross section. If the petiole was not twisted, its thickness was measured parallel to the blade surface.

Analyses of variance were done to test whether average blade areas and dry weights for each species were significantly different for individual trees, locations, or collection dates.

Analyses of covariance were done to test whether the relations between the natural logarithms of blade dry weight and petiole thickness, and blade area and petiole thickness were significantly different among trees, locations, collection dates, or certain interactions.

After significant effects were determined, data collected in Massachusetts and Connecticut in July and August were used to estimate regression equations of the following form:

$$\log W = \beta_0 + \beta_1 \log P$$
$$\log A = \beta_0 + \beta_1 \log P$$

where, W = blade dry weight; A = blade area; and P = petiole thickness. I assumed that the relationships were not the same for the four species or the two locations. For each species, I also assumed that the intercepts for July and August would be different, but the slopes would be the same.

To test the use of the regression equations for estimating expected blade dry weight and blade area of browsed leaves, a browsing experiment was undertaken on four additional trees. A quaking aspen and a red maple were selected at the Connecticut location, and a red oak and a white oak were selected at the Massachusetts location. Each tree received an early and a late browsing treatment.

In the early treatment, 50 leaves of each tree were artificially browsed with scissors after having been photographed with a dot grid superimposed over the blades. The blades were photographed again after treatment. The blade areas of each leaf before and after treatment were obtained from the photographs. These leaves were treated about May 15 and harvested about July 15.

An identical late browsing treatment was applied about July 15 and 50 leaves of the same four trees. Pre- and post-treatment blade areas were measured in situ with a portable electronic area meter. These leaves were harvested about August 15. All the harvested leaves were pressed and oven-dried before their blade dry weight, blade area, and petiole thickness were measured.

I use a special notation to describe the data from the browsing experiment. I use lowercase letters to represent browsed leaf measurements and capital letters to represent the whole-leaf values. The following symbols refer to the i^{th} leaf in the j^{th} treatment sample:

t_{ij} = blade area immediately after treatment,
T_{ij} = whole blade area immediately before treatment,
a_{ij} = blade area after harvest,
A_{ij} = predicted whole blade area after harvest,
w_{ij} = blade dry weight after harvest,
W_{ij} = predicted whole blade dry weight after harvest,
P_{ij} = petiole thickness.

The sample indexes are:

$j = 0$ for the early treatment sample, and
$j = 1$ for the late treatment sample.

The following symbols refer to the average blade values in the j^{th} treatment sample:

$\bar{t}_j$ = average blade area immediately after treatment,
$\bar{T}_j$ = average whole blade area immediately before treatment,
$\bar{a}_j$ = average blade area after harvest,
$\bar{A}_j$ = average predicted whole blade area after harvest,
$\bar{w}_j$ = average blade weight after harvest,
$\bar{W}_j$ = average predicted whole blade dry weight after harvest.

Estimates of log W_{ij} and log A_{ij} were made from petiole thickness measurements with the appropriate regression equations. One half of the residual variance of the regression equation was added to each estimate before it was transformed to its antilogarithm as an approximate correction for bias (see Finney 1941).

Defoliation of a given treatment sample can be defined as $1-(\bar{w}_j/\bar{W}_j)$, $1-(\bar{a}_j/\bar{A}_j)$, or $1-(\bar{t}_j/\bar{T}_j)$, where $(\bar{w}_j/\bar{W}_j)$, $(\bar{a}_j/\bar{A}_j)$, and $(\bar{t}_j/\bar{T}_j)$ are ratios of means. To determine whether the regression equations provided adequate estimates of whole leaf values, and consequently defoliation, the following differences were computed and tested for significant departure from zero with t-tests:

$$(\bar{t}_0/\bar{T}_0) - (\bar{w}_0/\bar{W}_0),$$
$$(\bar{t}_0/\bar{T}_0) - (\bar{a}_0/\bar{A}_0),$$
$$(\bar{t}_1/\bar{T}_1) - (\bar{w}_1/\bar{W}_1),$$
$$(\bar{t}_1/\bar{T}_1) - (\bar{a}_1/\bar{A}_1).$$

I also computed the difference $(\bar{t}_0/\bar{T}_0) - (\bar{a}_0/\bar{T}_1)$ for each species. This provided a way to determine if the proportion of defoliation in the early treatment samples had changed from any cause between treatment and harvest. The differences were very small, indicating little or no change. Because of the small differences, t-tests were not done. The variances of the ratios $(\bar{a}_j/\bar{A}_j)$ and $(\bar{w}_j/\bar{W}_j)$, were approximated by a formula that follows. It is given here for others who may want to estimate defoliation by my method and compute a standard error. A formula is given only for the variance of $(\bar{w}_j/\bar{W}_j)$. The formula for $(\bar{a}_j/\bar{A}_j)$ is identical except that a and A are substituted for w and W, respectively. The estimator[1] is:

$$v(\bar{w}_j/\bar{W}_j) = \frac{1}{n\bar{W}_j^2}\left[v(w_j) - 2\hat{\beta}_1\bar{w}_j \operatorname{cov}(X_jw_j) + \hat{\beta}_1^2 v(X_j)\bar{w}_j^2 \left(\frac{\bar{W}_j^2}{\bar{W}_j^2}\right)\right] +$$

$$\frac{\bar{w}_j^2 s^2}{n\bar{W}_j^2 v(X_j)}\left[\bar{X}_j^2 - \frac{2\overline{W_jX_j}\,\bar{X}}{\bar{W}_j} + \frac{\overline{W_jX_j}^2}{\bar{W}_j^2}\right] + \frac{s^4\bar{w}_j^2}{16n\bar{W}_j^2}$$

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[1] This estimator was derived by Gerald S. Walton, Mathematical Statistician, Northeastern Forest Experiment Station, Hamden, CT.

where $W_{ij} = \exp(s^2/2 + \hat{\beta}_0 + \hat{\beta}_1 X_{ij})$,

$X_{ij} = \log P_{ij}$,

s^2 = residual variance of the regression equation,

$$\overline{W_j^2} = \frac{\sum_i W_{ij}^2}{n},$$

$$\overline{W_j X_j} = \frac{\sum_i W_{ij} X_{ij}}{n}, \text{ and}$$

n = number of leaves in the j^{th} treatment sample.

RESULTS

From my analyses of variance of average blade areas and blade dry weights, I found that average leaf blade areas of the four species studied differ among trees in one location and among locations, but not among collection dates (Table 1). On a given tree, the average leaf blade area will not change significantly from June 15 to July 15, or from July 15 to August 15, unless a disturbance such as browsing occurs. Average leaf blade dry weights of quaking aspen and red oak differ among trees in one location, among locations, and among collection dates. Average blade dry weights of red maple differ among locations, but not among trees within one location, or collection dates. White oak average blade dry weights differ among locations and collection dates, but not among trees within locations.

From my analyses of covariance, I found that knowledge of petiole-thickness adds precision to estimates of both blade dry weight and blade area of all four species; but so does knowledge of tree, location, collection date, tree × collection date interaction, and location × collection date interaction.

The parameter estimates, standard errors of estimates, and coefficients of determination of the log blade dry weight, and the log blade area prediction equations are listed by species in Table 2. The performance of these equations in estimating the remaining fraction of expected blade dry weight and blade area in the early- and late-browsed samples are summarized in Table 3. This table contains the comparisons of $(\bar{t}_j/\overline{T}_j)$ (the ratio-of-means estimate of the remaining fraction of tissue just after treatment) with $(\bar{w}_j/\overline{W}_j)$ (the ratio-of-means estimate of the remaining fraction of blade dry weight after harvest), and $(\bar{a}_j/\overline{A}_j)$ (the ratio-of-means estimate of the remaining fraction of blade area after harvest).

In the early-browsed treatment, $(\bar{t}_0/\overline{T}_0) - (\bar{w}_0/\overline{W}_0)$ is significantly different from zero for the samples of red maple, red oak, and white oak, and $(\bar{t}_0/\overline{T}) - (\bar{a}_0/\overline{A}_0)$ is significantly different from zero for the samples of red maple and red oak. In the late-browsed treatment $(\bar{t}_1/\overline{T}_1) - (\bar{w}_1/\overline{W}_1)$ differs significantly from zero for the samples of red maple and red oak, although from a practical

Table 1. Level of significance for average blade areas and blade dry weights for sources of variation.

Source of variation	Species			
	Aspen	Maple	Red oak	White oak
	AVERAGE BLADE AREA			
Trees within location	0.01	0.05	0.01	0.05
Locations	.01	.01	.01	.01
Collection dates	NS	NS	NS	NS
	AVERAGE BLADE DRY WEIGHTS			
Trees within location	0.01	NS	0.01	NS
Locations	.01	.05	.01	.01
Collection dates	.01	NS	.05	.01

Table 2. Regression statistics for the blade dry weight and blade area prediction equations.

Species	Blade dry weight (g)					Blade area (cm)				
	Intercept July	Intercept August	Slope[a]	SE est.	R^2	Intercept July	Intercept August	Slope	SE est.	R^2
					CONNECTICUT					
Quaking aspen	– 2.731	– 2.660	1.671	0.324	0.70	2.231	2.183	1.429	0.324	0.61
Red maple	– 2.975	– 3.065	2.242	.260	.85	2.347	2.335	1.869	.293	.76
					MASSACHUSETTS					
Red oak	– 2.832	– 2.931	2.415	.252	.84	2.329	2.212	2.157	.295	.75
White oak	– 2.732	– 2.844	2.190	.266	.78	2.636	2.484	1.769	.290	.67

[a] Petiole thickness measured in mm.

Table 3. Ratio of means estimates of remaining blade area immediately after treatment ($\bar{t}_j/\bar{T}_j$), remaining blade dry weight after harvest ($\bar{w}_j/\bar{W}_j$), remaining blade area after harvest ($\bar{a}_j/\bar{A}_j$), and the standard errors of ($\bar{w}_j/\bar{W}_j$), and ($\bar{a}_j/\bar{A}_j$). Significance levels are based on t tests using approximate standard errors of ratio differences.

Species	$\bar{t}/\bar{T}$	$\bar{w}/\bar{W}$	SE($\bar{w}/\bar{W}$)	$\bar{a}/\bar{A}$	SE($\bar{a}/\bar{A}$)
		EARLY BROWSING TREATMENT			
Aspen	0.620	0.660NS	0.0301	0.594NS	0.0228
Maple	.608	.919**	.0457	.887**	.0393
Red oak	.611	.736**	.0329	.686*	.0303
White oak	.483	.565*	.0420	.472NS	.0318
		LATE BROWSING TREATMENT			
Aspen	0.550	0.507NS	0.0345	0.492*	0.0319
Maple	.509	.631**	.0304	.544NS	.0277
Red oak	.450	.495*	.0285	.461NS	.0270
White oak	.400	.416NS	.0235	.367*	.0197

NS – ratio is not significantly different from $\bar{t}_j/\bar{T}_j$
* – ratio is significantly different from $\bar{t}_j/\bar{T}_j$ at the .05 level
** – ratio is significantly different from $\bar{t}_j/\bar{T}_j$ at the .01 level

standpoint the result for red oak is probably insignificant for most purposes, and ($\bar{t}_1/\bar{T}_1$) – ($\bar{a}_1/\bar{A}_1$) differs significantly from zero for quaking aspen and white oak, but these differences may be insignificant from a practical standpoint.

The differences between ($\bar{t}_0/\bar{T}_0$) computed from the early-browsing treatment sample and ($\bar{a}_0/\bar{T}_1$) were small for all species. For quaking aspen, the difference was .015, for red maple .025, for red oak .068, and for white oak the difference was –.007.

DISCUSSION

The use of log blade dry weight or log blade area prediction equations to calculate the amount of leaf tissue a tree crown should contain could lead to erroneous defoliation estimates if insects browsed on the leaves early in the growing season but the crown was not sampled until July. Use of log blade dry weight equations might lead to significant underestimation of defoliation in red maple, red oak, and white oak. Use of log blade area equations might lead to significant underestimation in red maple and red oak.

The remaining fraction of blade area in the early-browsed samples did not change with time. My comparisons for each species of ($\bar{t}_0/\bar{T}_0$) with ($\bar{a}_0/\bar{T}_1$) suggest that petioles of leaves browsed early in the growing season do not reach the thickness they would if the blades were not browsed. Consequently, the remaining fraction of expected tissue is overestimated and defoliation is underestimated when the equations are used.

My comparison of ($\bar{t}_0/\bar{T}_0$) and ($\bar{a}_0/\bar{T}_1$) also suggests that knowledge of mean blade-area at a given time of year would be useful in estimating defoliation. However, in my analyses of variance of these quantities, I found that average blade-area differs from tree to tree for all four species used in this study. Moreover, many insect browsers do not leave enough whole leaves on a tree for one to obtain these estimates. The leaves remaining consist of leaf petioles with attached leaf blade fragments of indeterminable length and width.

Log blade area and log blade dry weight equations perform much better for a late browsing, probably because leaves have become mature and the petioles, for the most part, have stopped growing. I did find statistically significant differences between ($\bar{t}_1/\bar{T}_1$) and ($\bar{w}_1/\bar{W}_1$) in the late browsed sample of red maple and red oak, and between ($\bar{t}_1/\bar{T}_1$) and ($\bar{a}_1/\bar{A}_1$) in quaking aspen and white oak. However, except for red maple calculated on a dry-weight basis, these differences may be small from a practical standpoint.

Small differences are to be expected when the equations are used, in light of my analyses of covariance, in which I found significant differences in the intercepts of the log dry weight and the log blade area prediction equations among trees within locations for all four species. Accordingly, it would be better to use the log blade dry weight and log blade area prediction equations, which are derived from data from several trees, to estimate the combined defoliation of many trees. Collection of leaf samples very soon after browsing, before the leaves grow much, would probably facilitate use of blade petiole relations for estimating defoliation early in the growing season. The alternative to using the equations is to guess the quantity of tissue removed or remaining.

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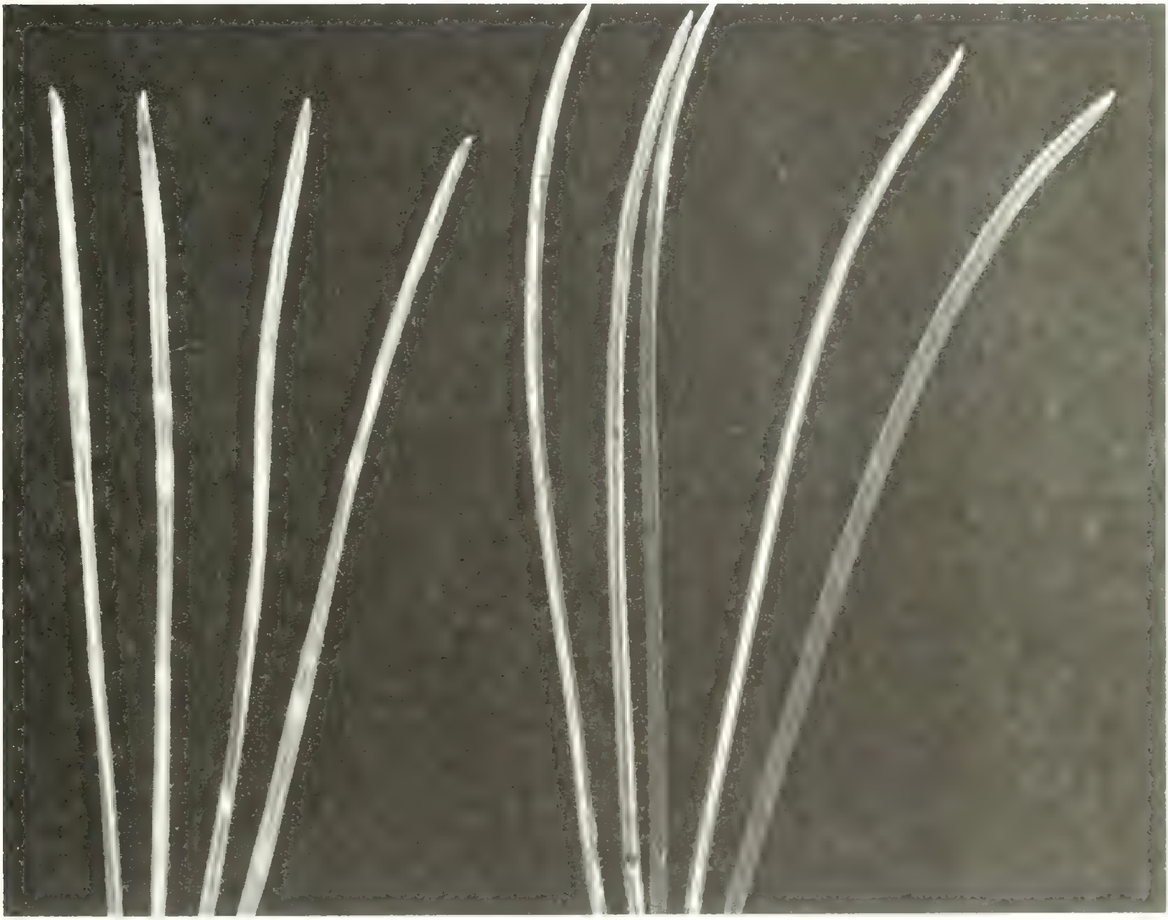
by Leon S. Dochinger and Stanford L. Arner

Needle Mottle in Eastern White Pine Seedlings: A Selective Parameter for Air Pollution Sensitivity



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Abstract

Positive correlations were established between morphological characteristics in eastern white pine seedlings and subsequent tolerance or sensitivity to air pollution 5 and 7 years after outplanting in Ohio plantations. Of 11 seedling variables, needle mottling was an accurate indicator of sensitivity or tolerance to air pollution. This characteristic, which may be genetically controlled, should allow for the detection and removal of sensitive white pines in the nursery during grading.

INTRODUCTION

QUANTIFYING GENETIC tolerance to air pollution is one of the more urgent priorities for forest management. Although large gene pools still exist for breeding, tree populations are constantly threatened and are being reduced by concentrations of ambient air pollutants. High levels of indigenous pollutants have damaged forest communities throughout the world (Dochinger 1971). Also, the adverse effects of long-term, ambient pollution over large expanses of forests are well documented (Dochinger 1972; Miller and Millican 1971).

Air pollution can create imbalances in the species composition of the plant community, which, in turn, may drastically influence the stability of the ecosystem. Although these changes are not totally understood, ambient pollution may change the genetic composition of the forest through the loss of intolerant genotypes, both by mortality and by impaired reproductive processes, such as flower production, pollen viability, and seed development (Houston and Dochinger 1977).

The variation in responses of trees to single and multiple pollutants is not completely understood. In conifers, genetic variation to injury by sulfur dioxide occurs in *Larix* Mill (Schonbach et al. 1964); by fluorides and sulfur dioxide in *Picea abies* (L.) Karst (Rohmeder et al. 1962; Rohmeder and von Schönborn 1968; Fer et al. 1972); by sulfur dioxide in *Pinus contorta* Dougl. (Enderlein and Vogl 1966); by fluorides and oxidants in *Pinus ponderosa* Laws. (Hepting 1964); by ozone and sulfur dioxide in *Pinus strobus* L. (Berry 1973; Dochinger et al. 1970; Houston 1974), and by fluorides and sulfur dioxide in *Pinus sylvestris* L. (Rohmeder et al. 1962; Vogl 1970).

Interspecific hybrids of *Larix* vary in sensitivity to sulfur dioxide (Enderlein et al. 1966) as do those of *Populus* L. to ozone (Jensen and Dochinger 1974) and to sulfur dioxide (Dochinger et al. 1972).

Intraspecific variation in sensitivity to ozone has been observed in *Acer rubrum* L. (Townsend 1974; Townsend and Dochinger 1974); to sulfur dioxide in *Picea abies* (Tzschacksch et al. 1969); to ozone and sulfur dioxide in *Pinus ponderosa* (Karpen 1970); to sulfur dioxide in *Pseudotsuga menziesii* (Mirb.) Franco (Enderlein and Vogl 1966); and to ozone and sulfur dioxide in *Platanus occidentalis* L. and in *Ulmus americana* L. (Santamour 1969).

This variation in sensitivity of tree species and populations to pollutants indicates significant genetic control. Therefore a program to select seedlings and seed sources of tolerant plants merits investigation. A preliminary step would be selecting for morphological, physiological, and biochemical markers. These genetic markers can be determined and classified only if quantitative or qualitative differences among plant populations can be measured.

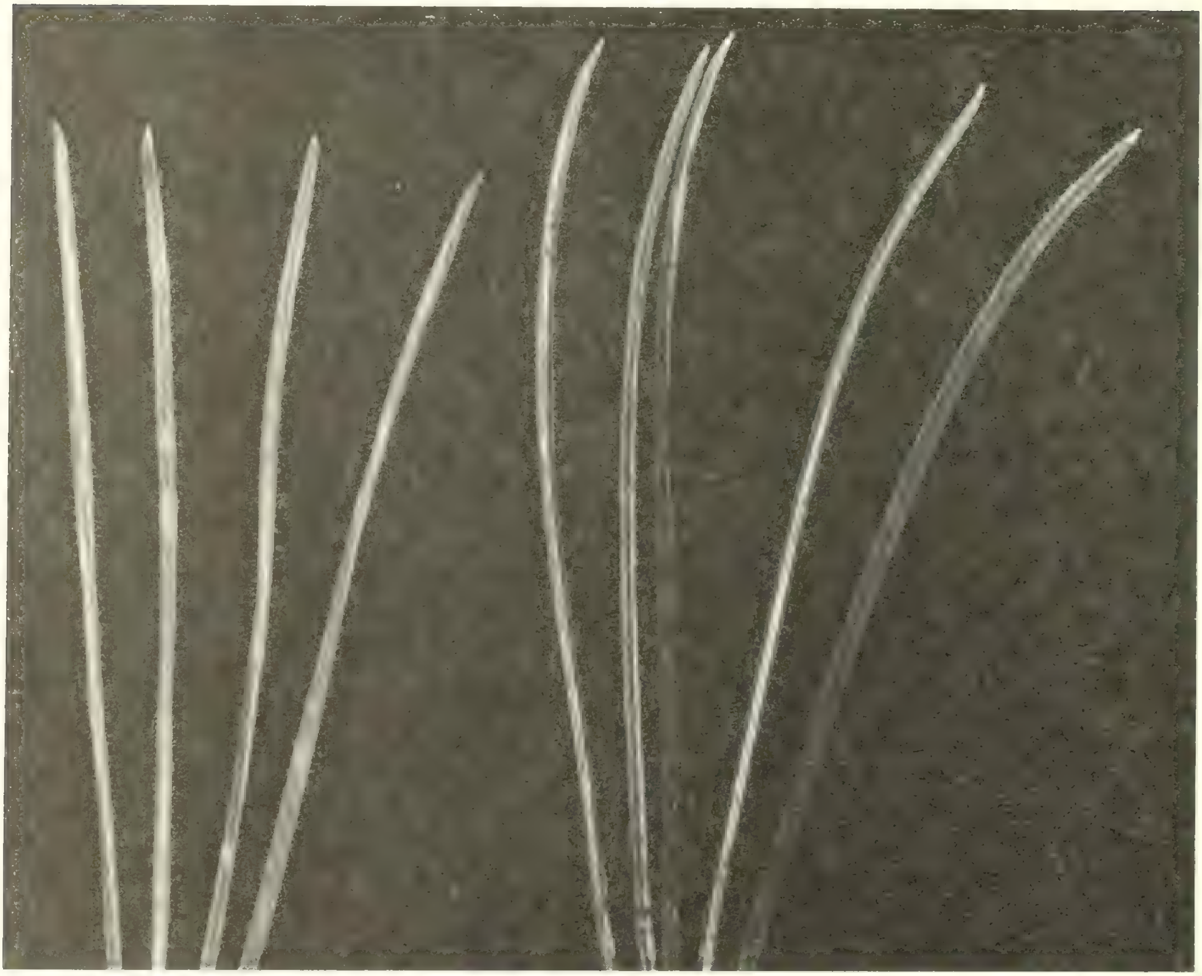
Our research on the sensitivity of white pine plants to air pollution suggested that mottling occurred on needles when sensitive trees were exposed to ambient pollution. Mottling was not observed when there were no pollutants in the vicinity of these white pines, but it reoccurred when they were again exposed to ambient pollution. Therefore we decided to determine the relationship between needle mottle and other morphological characteristics and tolerance to air pollution in seedlings of eastern white pine after outplanting. This paper reports on the responses of two eastern white pine plantings to ambient pollution over a 12-year period.

METHODS

In the first phase of the study, 2–0 seedlings of eastern white pine from state forest nurseries in Marietta and Zanesville, Ohio, were examined for chronic mottling of current-year needles (Fig. 1). Chronic injury was defined as irregular patterns of yellow discoloration (with indefinite margins) that occurred on both the abaxial and axial surfaces of the leaf.

Each seedling was rated for 11 characteristics: degree of foliage mottling; needle length; reten-

Figure 1.—Needle mottle is visible on a pollution-sensitive white pine fascicle, but not on the tolerant specimen.

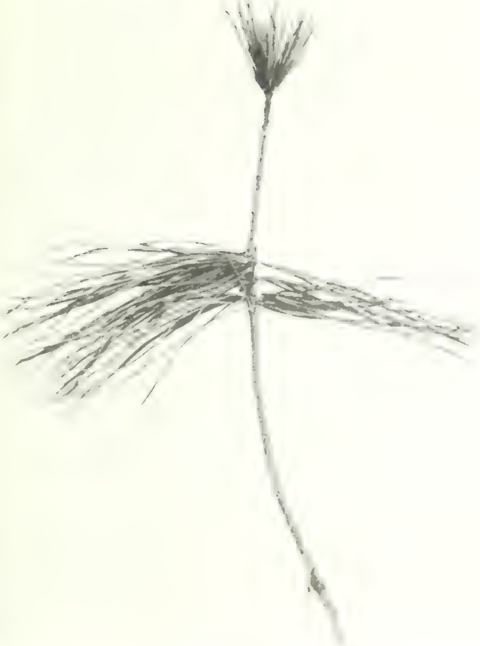


tion of first-year needles; current-year needle defoliation; necrotic spotting; needle tip necrosis; needle tip yellowing; presence or absence of juvenile foliage (Fig. 2); number of buds in terminal shoot; presence or absence of vestigial buds; and presence or absence of stalked buds (Fig. 3).

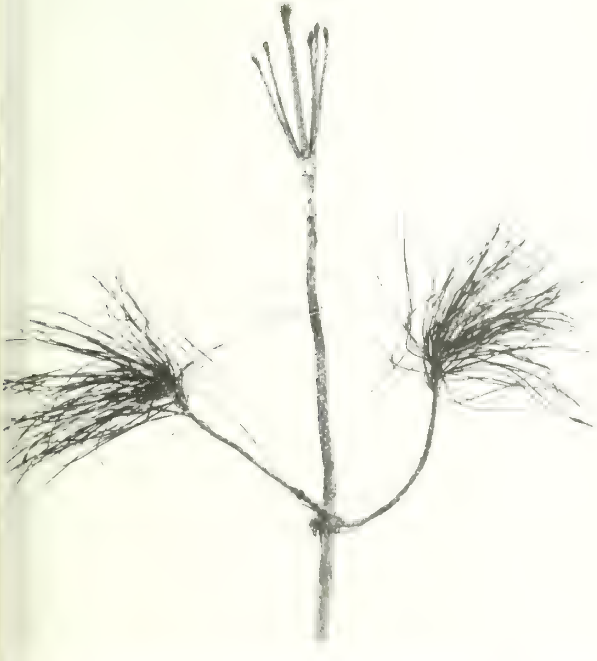
Foliage mottling was scored: 0 (none); 1 (less than 25 percent); 2 (25 to 50 percent); or 3 (greater than 50 percent). Needle length was scored: 0 (less than 1 inch); 1 (1 to 2 inches); or 2 (greater than 2 inches). The number of buds was scored: 0 (less than 3), or 1 (greater than 3). The remaining variables were scored: 0 (no), or 1 (yes).

We selected 400 plants, 200 with mottling and 200 without mottling. Seedlings were planted randomly in a plantation in the Blue Rock State Forest in southern Ohio during the spring of 1963. In the immediate vicinity of Blue Rock State Forest are several sources of stack gases, including 500,000 and 1,000,000-kilowatt electric power plants. For all trees, ratings for survival and sensitivity to air pollution were recorded each year for 5 years.

The second phase of the study was begun in 1968 when an additional planting was made in the Blue Rock State Forest. In each of 20 randomly chosen rows we planted 10 seedlings of 2–0 white pines—with and without mottling. Similar data for these trees were collected each September for 7 years.



ure 2.—Morphological characteristic of juvenile iage on white pine.



ure 3.—Morphological characteristic of stalked ds on white pine.

RESULTS AND DISCUSSION

A nonparametric classification technique was used to relate white pine individuals to measured seedling characteristics (Cochran and Hopkins 1961). The presence or absence of mottling on the seedlings was an excellent criterion for measuring sensitivity to ambient concentrations of air pollutants in white pine trees in Ohio plantations.

5-year planting

The value for each variable in Table 1 represents the proportion of white pine seedlings—originally designated as tolerant or sensitive—that remained

Table 1.—Percentage of white pine seedlings, originally designated as tolerant or sensitive to air pollution, that remained tolerant or sensitive 5 years after outplanting.

Characteristic	White pine seedlings	
	Tolerant	Sensitive
Foliage mottling		
None	95	--
Less than 25%	4	21
25 to 50%	1	50
Greater than 50%	—	29
Needle length		
1 inch	2	8
1 to 2 inches	55	84
Greater than 2 inches	43	8
Current-year needle retention		
Yes	34	—
No	66	100
Current-year needle defoliation		
Yes	99	99
No	1	1
Necrotic spotting		
Yes	67	12
No	33	88
Needle necrosis		
Yes	94	82
No	6	18
Needle tip yellowing		
Yes	39	48
No	61	52
Juvenile needles		
Yes	100	93
No	—	7
Number of buds		
Less than 3	98	86
More than 3	2	14
Stalked buds		
Yes	31	37
No	69	63
Vestigial buds		
Yes	100	99
No	—	1

tolerant or sensitive to air pollution 5 years after outplanting. During the first year, 59 seedlings did not survive—40 in the tolerant group and 19 in the sensitive group. These seedlings were not included in the final tabulation because responses to air pollution were not apparent at the time of death; also, survival patterns did not indicate significant differences between the two groups. Of the 181 surviving plants designated as sensitive because of mottling, 173 remained sensitive. However, all of the 160 surviving seedlings without needle discoloration remained tolerant.

7-year planting

For the 7-year planting, we observed similar responses to air pollution. All of the 100 tolerant white pines remained tolerant (including five plants that died during the study). In the sensitive group, 97 of 100 seedlings with mottled foliage remained sensitive to air pollution (including five that died during the study).

On the basis of results for both studies, it seemed reasonable to classify all white pine seedlings with no mottling as tolerant and those with mottling as sensitive to atmospheric pollution. This conclusion nullified the necessity of considering the remaining 10 variables because the results would not have markedly affected the accuracy of predictions of plant performance.

The similarity in values for mottling between white pine seedlings and forest trees indicates that the nursery stage is an excellent one for identifying genetic differences in sensitivity to air pollution. Since nursery seedlings are exposed to fairly uniform conditions, sensitive individuals can be removed during grading. And widespread sublethal and lethal concentrations of air pollution coupled with extreme sensitivity of white pines to these levels allow the detection and removal of sensitive pines. Cooperation among research specialists, commercial nurserymen, forest managers, and arborists would be required to apply these techniques successfully.

The use of these techniques require selection for morphological, physiological, and biochemical markers. These genetic markers must be tested by controlled laboratory fumigation regimes and by field exposure to ambient pollution. The merits of laboratory study are considerable, but ultimate decisions on plant performance must be determined in the field before practical recommendations can be made.

Field plantings may present difficulties in measuring the impact of air pollution. All factors must be evaluated in testing promising phenotypic and genotypic characteristics. The interactions of hereditable factors of the plant with its total environment must be evaluated as possible variations in response to pollution. Finally, traditional factors such as stem form and volume must be considered in selecting for tolerance to air pollution in a long-term breeding program.

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by Albert T. Schuler

THE INSULATION BOARD INDUSTRY — AN ECONOMETRIC ANALYSIS

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Abstract

An econometric model of the domestic insulation board industry was developed to identify and quantify the major factors affecting quantity consumed and price. The factors identified were housing starts, residential improvement activity, disposable personal income, productivity, pulpwood and residue prices, and power costs. Disposable personal income was the most important of these factors, affecting both quantity and price. Annual projections of quantity and price show quantity increasing by 30 percent and price by 106 percent by the year 1990.

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INTRODUCTION

SPIRALING ENERGY COSTS have had a significant impact on the insulation materials industry. Insulation prices rose approximately 15 percent in 1977 alone, and there are growing shortages of insulation materials. Quantitative market information is needed to help stabilize these markets.

The insulation board industry is an integral part of the insulation materials market. Insulation board sheathing is the most widely used sheathing material for America's frame homes. Acoustical ceiling tile is a basic product for sound conditioning of homes, apartments, and other structures. Building board is a general purpose insulation board used for ceilings and walls in farm buildings and in attic and basement remodeling. Roof insulation board is used for flat roof construction.

The insulation board industry comprises 12 plants that produce primarily insulation board and another 6 plants that produce both insulation board and hardboard. These plants have a combined annual capacity of approximately 3.2 billion square feet (on a ½-inch basis).

A basic problem the industry shares with many other wood products industries is a lack of quantitative price-quantity information describing the markets in which it operates. This presents difficulties for the industry and its individual members in both short-term and long-term planning.

Short-term planning (year to year) requires a knowledge of the important factors affecting consumption and price of insulation board. For example, if the industry knew that consumption of insulation products were very sensitive to housing starts, they could monitor projections of that index and alter production levels accordingly. Quantification of the relationships between these exogenous variables and consumption or price levels of insulation board would enable the industry to respond quickly to shifts in market conditions by altering production schedules and pricing policies, to the mutual benefit of consumer and producer.

In any competitive industry, sound long-term planning (10 to 15 years) is necessary to the survival of individual firms and the industry itself. This type of planning requires knowledge of future consumption and market price levels. Long-term planning determines what investments will be required for new plant and equipment, for example. Should plant capacity be expanded to meet anticipated demand? Firms in the industry must make decisions now about future plant development and expansion, because it takes time to raise the necessary capital and build plants.

The consumer benefits indirectly from sound planning by industry. For example, insulation products such as mineral batts, fiberglass batts, and foam are in short supply. The surge in demand was not anticipated and has resulted in consumer inconvenience and higher prices. Because of the shortage, housing construction has been unnecessarily delayed. In addition, producers of these products have lost potential profits on lost sales.

Consumption projections of all forest-related products, including insulation board, are also needed by forest planners to evaluate current forest programs, establish timber-growth goals, and aid in formulating forest policies and proposed programs.

An econometric model of the insulation board industry was developed in this study to provide needed market information. Specific objectives of the study were: (1) to identify and quantify the variables affecting the quantity of insulation board consumed and its price; and (2) to project equilibrium quantity and price levels to the year 1990. A related objective was to determine the feasibility of using econometric models to help the forest planners determine future forest resource requirements from a knowledge of industry needs. The Forest Service has been given the responsibility of periodically assessing forest resource requirements by the Resources Planning Act and the National Forest Management Act of 1976.

FRAMEWORK OF ANALYSIS AND METHODOLOGY

An equilibrium model consisting of a demand and supply equation and an identity was developed to study the insulation board market. The identity is necessary for demand-supply equilibrium. The general form of the hypothetical linear model is:

$$q_d = \alpha_d P_d + \beta_o + \beta_1 X_{d1} + \ldots + \beta_p X_{dp} + e_d$$
$$q_s = \alpha_s P_s + \gamma_o + \gamma_1 X_{s1} + \ldots + \gamma_q X_{sq} + e_s$$
$$q_d = q_s$$

where:

q_d = quantity demanded
q_s = quantity supplied
$P_d = P_s$ = price of insulation board
$X_{d1} \ldots X_{dp}$ = demand variables
$X_{s1} \ldots X_{sq}$ = supply variables
α_d, α_s = regression coefficients for price
$\beta_1 \ldots \beta_p$ = regression coefficients for independent demand variables
$\gamma_1 \ldots \gamma_q$ = regression coefficients for independent supply variables
e_d = demand error term
e_s = supply error term
β_o, γ_o = intercept terms for demand and supply equations, respectively

The model can be written in matrix notation as:

$$\mathbf{Y} = \alpha \mathbf{P} + \beta \mathrm{X} + \mathbf{e}$$

where:

$$\mathbf{Y} = \begin{bmatrix} q_d \\ q_s \end{bmatrix} \quad \alpha = \begin{bmatrix} \alpha_d & O \\ O & \alpha_s \end{bmatrix} \quad \mathbf{P} = \begin{bmatrix} P_d \\ P_s \end{bmatrix}$$

$$\beta = \begin{bmatrix} \beta_o \, \beta_1 \ldots \beta_p \, O \, O \ldots O \\ O \, O \ldots O \, \gamma_o \, \gamma_1 \ldots \gamma_q \end{bmatrix} \qquad \mathbf{e} = \begin{bmatrix} e_d \\ e_s \end{bmatrix}$$

and

$$\mathbf{X} = [1 \, X_{d1} \ldots X_{dp} \, 1 \, X_{s1} \ldots X_{sq}]'$$

The model depicted is an equilibrium model that accounts for the interaction between demand and supply and the interdependence of prices and quantities. It is based on annual observations of each variable over the sample period 1950 to 1974. The data sources used were: housing starts, value of residential improvements, disposable personal income, and power costs (U.S. Bureau of Census 1950-1974); productivity (U.S. Bureau of Census 1954-1972); pulpwood and residue prices, insulation board consumption, and insulation board price (Phelps 1975).

Ordinary least squares (OLS) analysis has been used in the past to estimate parameters in demand and supply equations. However, demand and supply forces interact to determine market clearing levels of price and quantity. Under such a simultaneous system, OLS will yield biased and inconsistent estimators of the parameters of the demand and supply relationships, because the dependent variable (price) on the right hand side of the demand and supply equations is correlated with the error terms. The estimators are inconsistent because the bias persists for even infinitely large samples.

Consequently, the two-stage least squares (2SLS) procedure was used to estimate the parameters in the demand and supply equations. It yields estimators that are consistent. Also, there is evidence suggesting that the bias is reduced (relative to OLS) depending on the degree to which the system is overidentified (Christ 1966). In fact, this estimating procedure was specifically designed for use with overidentified simultaneous systems. Two-stage least squares was selected over other simultaneous equation procedures because it reduces computation. Computer algorithms such as the SYSREG routine in SAS–76 (Barr et al. 1976) are readily accessible and inexpensive to use.

SPECIFICATION OF INSULATION BOARD MARKET MODEL

Demand for insulation board is closely correlated with activity in the building construction industry. In fact, 95 percent of insulation board is consumed by the construction industry in one form or another. The residential construction industry is by far the major consumer of insulation board, so housing starts and home improvement and remodeling activity were expected to affect demand.

Disposable personal income is postulated to affect insulation board demand in several ways. Real personal income is a major determinant of headship—the proportion of the population that head separate households (Marcin 1972). As such, it indirectly affects housing demand. Income levels also affect remodeling and home improvement activity. Construction activity is necessarily correlated with the economic health of the Nation and personal income levels are a good measure of economic health.

Economic theory suggests that prices of substitutes will be directly related to demand. In the exterior sheathing market, the major substitute over the past 20 years has been softwood plywood. However, plywood is now used primarily at the corners of frame houses for additional strength and is, therefore, not a direct competitor for sheathing purposes. Insulation batt, both mineral-based and fiberglass, is used for interior sheathing to provide additional insulation for walls, attics, and floors. As such, it is not considered a direct substitute for insulation board sheathing. Gypsum wallboard is a substitute for building-grade insulation board, but this is a relatively minor market (in proportion of total insulation board sales), and it was felt that it should not significantly affect overall demand for insulation board. For these reasons, I decided that substitutes do not play a significant role in determining overall demand for insulation board. This may not be the case, however, for market models for individual insulation board products such as sheathing or building board.

Economic theory suggests that price is inversely related to demand. My first preference was to use actual insulation board prices, but there are four major products listed in *Wholesale Prices and Price Indexes*. Calculating a weighted average price for each year over the sample period proved extremely cumbersome because the relative weights of these products change periodically. Consequently, I decided to use the insulation board price index (1967 = 100) in lieu of actual prices.

The demand relationships thus specified are:

Variable	*Expected relationship to demand*
Insulation board price index (1967 = 100)	Negative
Housing starts (1000 units)	Positive
Remodeling and home improvement activity (millions of $, 1967)	Positive
Disposable personal income (billions of $, 1967)	Positive

The supply of insulation board is affected by several major variables. Raw material costs will naturally affect production costs. Insulation board plants utilize either roundwood or residues, depending on relative prices and availability. Firms in the Northwest, for example, rely almost entirely on softwood plant residues. Firms in the North and South use varying amounts of plant residue and roundwood. Because this study was national in scope, a weighted average price of plant residues and roundwood was used in the supply relationship. Weights used were determined by regional shipment patterns.

Another major cost item is fuel and power. Both electricity and natural gas are used to heat plants and run various machines. Therefore, an average price index (1967 = 100) for electricity and natural gas was used in the supply relationship.

Productivity will affect the efficiency with which the industry combines production inputs, and thus influences the supply of insulation board. Productivity will also provide a measure of technological change, which also affects supply.

Economic theory postulates that price will affect supply in a positive direction. There is no reason to believe that this would not be true for the insulation board industry.

Hardboard prices were assumed to influence insulation board supply because some of the newer plants are capable of producing either product. They can shift a percentage of production from one product to another in response to current market conditions. For example, if hardboard prices are strong, these plants will shift a greater percentage of their production to hardboard. Although one-third of the insulation board is produced in these plants, they produce only 15 percent of the total hardboard production. Therefore, although hardboard prices may affect insulation board supply, activity in the insulation board industry should not affect hardboard prices— hence hardboard prices were treated as an independent variable in this study. This conclusion is important because if hardboard prices were affected by the insulation board industry, the model would have to be expanded to include a demand- supply relationship for the hardboard market.

Since imports averaged less than 3 percent annually over the sample period, I decided that imports could be ignored without seriously distorting the supply-demand relationships.

The supply relationships thus specified are:

Variable	*Expected relationship to supply*
Insulation board price index (1967 = 100)	Positive
Productivity (value of shipment in $, 1967, per man-hour of production workers)	Positive
Pulpwood and residue prices	Negative
Power and fuel price index (1967 = 100)	Negative
Hardboard price index (1967 = 100)	Negative

ESTIMATED DEMAND AND SUPPLY EQUATIONS

Three major statistical criteria were used to decide whether to retain postulated variables in the demand and supply equations. One criterion was that the beta coefficient be greater than its standard error. This is a commonly accepted level for use in econometric models dealing with simultaneous equation systems. The Durbin-Watson D Statistic was used to test for serial correlation in the residuals in the model. Serial correlation is often caused by the omission of important independent variables and/or misspecification of the functional form of the equation. If the equation passes the Durbin-Watson test, this is a partial indication that the important variables are included and the functional form is correct.

The estimated model also had to be identified. This means that the specified demand relationship includes only variables that affect demand and the supply relationship includes only ones that affect supply. Statistical requirements for identification had to be met in order to determine accurately the parameters in the projection equations for quantity consumed and price of insulation board.

A major economic criterion used was that the parameters in the estimated equations have the correct sign.

Estimated model

The following model was estimated using the 2SLS estimating procedure. The standard errors of estimates are in parentheses.

Demand q_d^* $$= -759980 - \underset{(8371)}{26266.27}\,(\text{Price})^* + \underset{(166)}{636.51}\,(\text{Housing Starts}) + \underset{(53)}{226.10}\,(\text{Residential Improvements}) + \underset{(796)}{5947.81}\,(\text{Disposable Personal Income})$$

Durbin-Watson D Statistic = 2.11

Supply q_s^* $$= 434386 + \underset{(8597)}{34340.18}\,(\text{Price})^* + \underset{(24046)}{163248.35}\,(\text{Productivity}) - \underset{(58781)}{101250.87}\,(\text{Pulpwood and Residue Prices}) - \underset{(11647)}{14637.49}\,(\text{Power and Fuel Prices})$$

Durbin-Watson D Statistic = 1.55

---

*Dependent variable.

The estimated demand equation was judged satisfactory in that the relationships specified met our statistical and economic criteria. Each variable had a beta coefficient not less than its standard error; the Durbin-Watson D Statistic was in the nonsignificant range; and each variable had the anticipated sign.

The estimated supply equation was not as satisfactory because hardboard prices did not appear to be as important as originally assumed. Its beta coefficient was approximately one-half its standard error and did not have the expected sign. Inclusion of hardboard prices in the supply equation also reduced the Durbin-Watson D Statistic to a level approaching significance. Therefore, hardboard prices were not retained in the final estimated supply equation.

One possible reason for the poor performance of hardboard prices is that only a few of the newer plants have the capability to shift efficiently from hardboard to insulation board production and vice versa. Therefore, this capability is probably not adequately reflected in the data base used to estimate the supply equation.

The remainder of the specified relationships were retained in the final estimated supply equation. Each of these variables had a beta coefficient greater than its standard error and had the correct sign.

PRICE AND QUANTITY PROJECTIONS

The estimated demand and supply equations were solved simultaneously to yield reduced form (solved structural) equations for projecting insulation board price and quantity.

The projection equations for insulation board price and quantity are:

Quantity = −242354 + 360.65 (Housing Starts) + 128.11 (Remodeling Activity) + 3370.09 (Disposable Personal Income) + 70750 (Productivity) − 43881.11 (Pulpwood and Residue Prices) − 6343.52 (Power Costs)

Price = −19.71 + .0105 (Housing Starts) + .0037 (Remodeling Activity) + .0981 (Disposable Personal Income) − 2.6936 (Productivity) + 1.6706 (Pulpwood and Residue Prices) + .2415 (Power Costs)

Elasticity measures

A measure of the relative importance of the variables affecting quantity or price can be determined by their respective elasticities. Elasticity is simply the percent change in the dependent variable associated with a 1 percent change in one of the predetermined variables, holding everything else constant. Elasticities can be calculated as follows:

$$\xi_i = \frac{dY}{dX_i} \cdot \frac{X_i}{Y} \qquad (2)$$

where:

Y = dependent variable (price or quantity)

X_i = predetermined variable

ξ_i = elasticity

The reader should be cautioned that elasticity is only a partial measure of impact. The effect that predetermined variables have on price or quantity can be either offset or amplified by other variables—both those included in the model and those outside the model.

The following elasticities were calculated for quantity and price of insulation board at 1974 levels for all variables.

Quantity	
Disposable personal income	.71
Productivity	.50
Remodeling activity	.48
Pulpwood and residue prices	−.41
Power costs	−.32
Housing starts	.16

Price	
Disposable personal income	.49
Productivity	−.45
Pulpwood and residue prices	.37
Remodeling activity	.33
Power costs	.29
Housing starts	.11

All of the quantity and price elasticities were inelastic (≤ 1), meaning that a 1 percent change in any one variable will result in less than a 1 percent change in quantity or price.

To illustrate the use of these elasticities, the effect of changes in disposable personal income on quantity is used. An elasticity of .71 means that an increase of 1 percent in income will increase quantity by .71 percent or 22,542,485 square feet (based on 1974 levels). Remembering that this is only a partial effect, one must also consider whether an increase in income affects housing starts, remodeling activity, or any other variable that affects quantity.

Elasticity measures can provide the insulation board industry with useful insights into the sensitivity of quantity or price to changes in housing starts, income levels, power costs, etc. Knowledge of these effects should help industry leaders cope more effectively with changing market conditions. Assessment of predictive ability

Assessment of predictive ability

A major objective of the study was to make projections to the year 1990 for insulation board quantity and price. Before this was done, the equations were evaluated for predictive ability. The best measure of predictive ability would be to compare projections with observed values. Unfortunately, sufficient observations could not be reserved from the available time series because the sample was already small. Therefore, Theil's

Table 1.—Turning point predictions.

Prediction	Quantity	Price
Proportion of predicted turning points that were correct	0.64	0.17
Proportion of actual turning points predicted	.64	.50

Turning points are changes in trend direction.

(1975) inequality coefficient[1] was used to evaluate predictive ability for projecting levels and changes in levels over the sample period. The coefficients for level projections were determined to be .05 for quantity and .03 for price, with values near zero implying perfect prediction. However, predictive ability for projecting changes in levels was not as satisfactory as indicated by coefficient values of .84 and .78 for quantity and price, respectively.

To further assess predictive ability, predicted turning points were compared with observed points over the sample period (Table 1). The values in Table 1 indicate that the turning point predictions for quantity were much more satisfactory than those for price. This is understandable because prices usually fluctuate more than quantity.

On the whole, validation results are good and provide support for the hypotheses underlying the model. Validation results indicate that the model is better suited for projecting quantity and price levels rather than changes in levels.

Projections for predetermined variables

Before projections could be made for quantity and price, forecasts had to be obtained for each of the predetermined variables over the projection period. Wherever possible, projections by other sources were utilized; housing start projections by Marcin[2] are a case in point. Disposable personal income is projected by many government and private sources, with the concensus in the neighborhood of 3 percent real annual increase. Projections for power costs, pulpwood and residue prices, and productivity were based on the assumption that they would continue the rate of increase established over the period 1963 to 1974. Real rates established for these variables were 6.18 percent, 4.09 percent, and 3.58 percent, respectively. Remodeling activity has picked up considerable momentum since 1972, due in part to the rapid increase in new home construction costs and mortgage financing. Therefore, the real average annual rate of increase between 1972 and 1975 (approximately 5 percent) is expected to continue. It may increase, because new home construction costs and financing are expected to continue increasing.

These figures provided the basis for the medium-level projections for insulation board price and quantity. But to provide flexibility to the projections, quantity and price were also projected under somewhat more optimistic (high-level) and pessimistic (low-level) economic conditions. The independent variables in the system can fluctuate considerably from their norms; values of plus or minus 15 percent are not unusual. Therefore, the high-level projections are based on the assumption that the independent variables will increase at a rate 15 percent greater than the medium-level rate. For example, it was assumed real disposable personal income would increase at a 3.45 percent annual rate, instead of the medium level of 3 percent. The low-level projections are based on the assumption that the independent variables will increase, but at a rate 15 percent less than the medium-level rate. The corresponding rate used for personal income, for example, was 2.55 percent. Similar assumptions were made for the remaining independent variables in the system for both the high-level and low-level projections.

Projections for quantity and price

Tables 2 and 3 present projections for insulation board quantity and price to the year 1990. Although quantity is expected to increase by only 30 percent (medium level), price is projected to increase by 106 percent (over 1976 observed levels) by the year 1990. These figures can be translated into average annual rates of increase of 2.18 and 7.7 percent, respectively, for quantity and price. The projected rate for quantity is somewhat less

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[1] The inequality coefficient compares predicted with actual values via the following relationship:

$U = (\Sigma(P - A)^2/N)^{1/2}/(\Sigma A^2/N)^{1/2}$

where:

P = predicted values (P_i) or changes ($P_i - P_{i-1}$)
A = actual values or changes
N = sample size

[2] Unpublished paper titled "The outlook for housing by type of unit and region: 1978 to 2020" by Thomas Marcin. For. Products Lab., Madison, Wis.

Table 2.—Quantity projections for insulation board in thousand square feet, ½-inch basis.

Year	High	Medium	Low
1977	3599051	3444026	3319650
1978	3753199	3537544	3397172
1979	3903312	3705164	3527122
1980	4061364	3848708	3637825
1985	4513892	4252712	3941013
1990	4913886	4571411	4183080

Quantity = domestic production + imports − exports.

Table 3.—Insulation board price index projections (1967 = 100)

Year	High	Medium	Low
1977	180.6	175.9	172.0
1978	191.0	183.7	178.6
1979	201.7	194.0	187.0
1980	213.0	204.0	195.1
1985	279.8	260.1	239.9
1990	368.7	330.3	294.0

than the 2.4 percent growth rate experienced by the industry over the past 10 years. However, future price increases are expected to be much greater than the relatively stable annual rate of .81 percent recorded over the past 10 years. Rapidly escalating energy costs are a major factor in this development.

CONCLUSIONS

The market model developed in this study can be quite useful by providing a mechanism for industry planners to assess the impact of important influences such as housing starts, disposable personal income, power costs, etc., on insulation board quantity and price. The elasticity measures developed will indicate partial impacts of changes in these variables. Knowledge of impacts is necessary for planners to cope effectively with fluctuating market conditions and provide the consumer with desired products at the lowest cost. Market models provide information that can be used to help prevent the serious market imbalances that often result in supply shortages and high prices—such as those currently occurring in some segments of the wood products industry.

Quantity projections show the industry continuing to grow, but at a rate somewhat slower than that experienced over the past 10 years. Quantity is projected to increase by 30 percent by the year 1990, necessitating an increase in current plant capacity of 20 to 25 percent. Price is projected to increase at the relatively rapid real annual rate of 7.7 percent, which provides incentives to increase supply.

The projections of this study may be of less use for year-to-year planning because the performance of turning point forecasts over the sample period is questionable. Although 64 percent of the predicted turning points were correct for quantity, only 17 percent of those for price were correct. Another concern is that the model was not tested adequately for predictive ability. Unfortunately, sufficient observations could not be reserved from the available time series.

Results from this study suggest the potential of econometric models to provide forest planners with valuable information on future industry trends. An estimate of future product demand for each wood-using industry, including the insulation board industry, is needed to determine future forest resource requirements. This knowledge is needed to evaluate current and proposed forest programs and to guide forest policy.

The reader is cautioned to remember that when using this or any other econometric model, he must recognize changes which may conflict with the assumptions employed. For instance, rising energy costs are just beginning to have an impact on the national economy and life styles. The energy situation is already bringing about changes in construction with the introduction of new products that emphasize thermal properties. In 1977, there has actually been a decrease in the use of insulation board sheathing because of inroads by other sheathing products such as the polystyrene and polyurethane foams.[3] The analyst using this or any other model must recognize that changes can occur, and that regardless of a model's past predictive accuracy, altered conditions will necessitate a new look at its assumptions and conclusions. The projections developed in this study are simply estimates of what the quantity and price of insulation board may be if assumptions regarding future housing starts, disposable personal income, etc., materialize.

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[3] Information obtained from a letter to the author from the Amer. Board Products Assoc., dated Nov. 16, 1977.

Need for future studies

This study is one of several such studies needed to provide better market information for the various industries that use wood products. There is an urgent need for a concentrated effort to analyze the various hardwood markets, including hardwood plywood, veneer, and lumber. There have been several excellent studies of softwood markets (McKillop 1967, Adams 1977), but no similar studies have been completed (to this author's knowledge) on the major hardwood markets.

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SERPENTINE END MATCHING: A TEST OF VISUAL PERCEPTION

by Bruce G. Hansen and Charles J. Gatchell

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Abstract

In tests of gross perception of Serpentine end matched (Sem) joints in oak and cherry display panels, there were no significant differences between the number of times the non-Sem panels were chosen and the number of these selections that could be attributed to chance. Results of separate tests of sensitivity of perception of Sem joints showed that the most conspicuous joints in oak and cherry panels were chosen most often, and that the least conspicuous joints were detected least often. Given proper selection of pieces to be end matched, and moderate finishing, Sem joints are difficult to detect—even by those who are well-informed about Serpentine end matching.

SERPENTINE END MATCHING (Sem) is an end joining technique that overcomes objections to straight end joints in furniture panels. The curved end joint is based on a sine wave and is machined with precision by a numerically controlled router. Sem is a new way to joint short pieces of low-grade lumber.

When well-matched pieces of wood are end joined, the joints are difficult—often nearly impossible—to see with the naked eye. The question then arises: how much matching of grain and color is necessary to make the joints imperceptible? The answer is important in defining the potential of Serpentine end matching (Fig. 1).

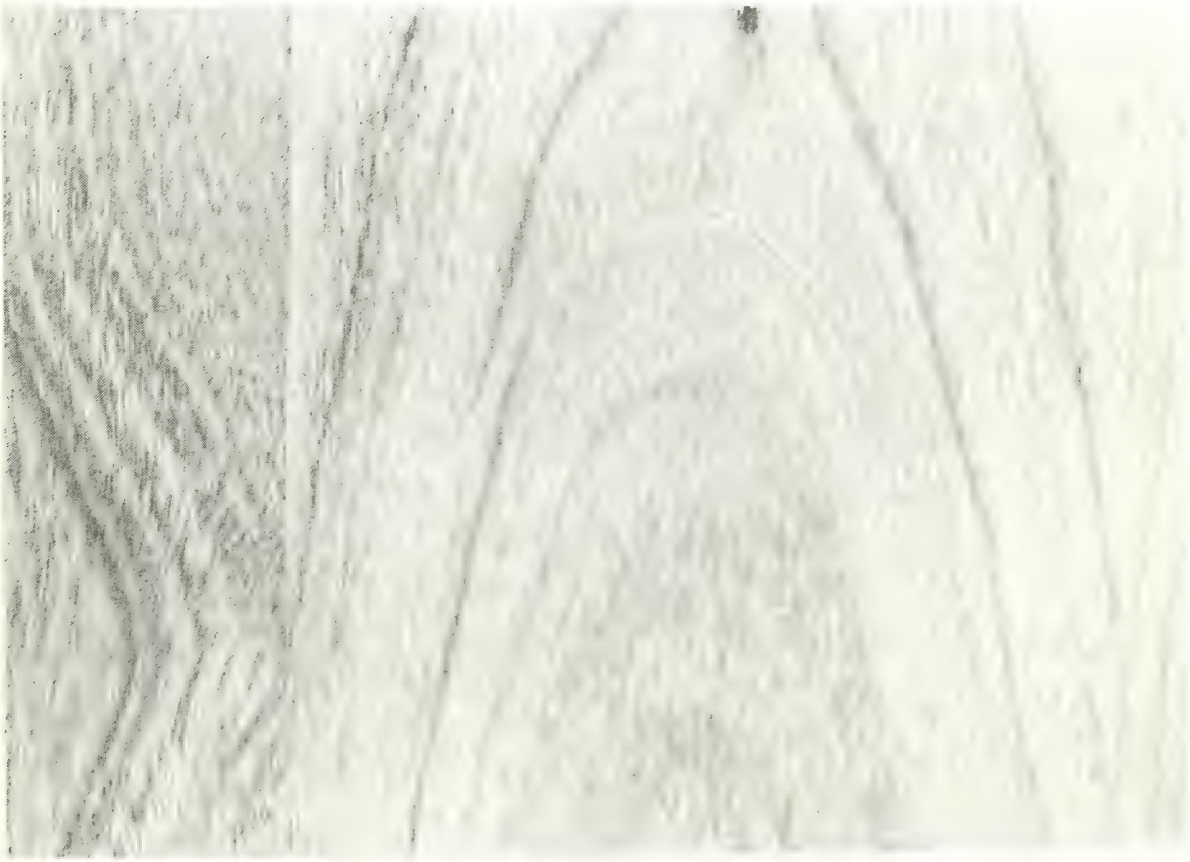
PERCEPTION TEST

To evaluate perceptions of Sem joints, a two-part test was given to participants of the 5th Annual Meeting of the Hardwood Research Council. Most of these participants were dimension producers, furniture manufacturers, design consultants, and others with an intimate knowledge of hardwoods and furniture manufacture.

Part I

We first wanted to test the gross perception of Sem joints. Could participants identify the curved end joints if they were unaware of Serpentine end

Figure 1.—Close-up of Serpentine end joint in cherry panel.



matching? We used a "triangular" test in which observers examined displays of oak and cherry panels. Each display consisted of two, four-piece panels and one "odd" three-piece panel. All panels were the same size. Each four-piece panel contained a Sem joint; the single three-piece panel did not. Forty-seven participants were asked to select the odd non-Sem panel in each display.

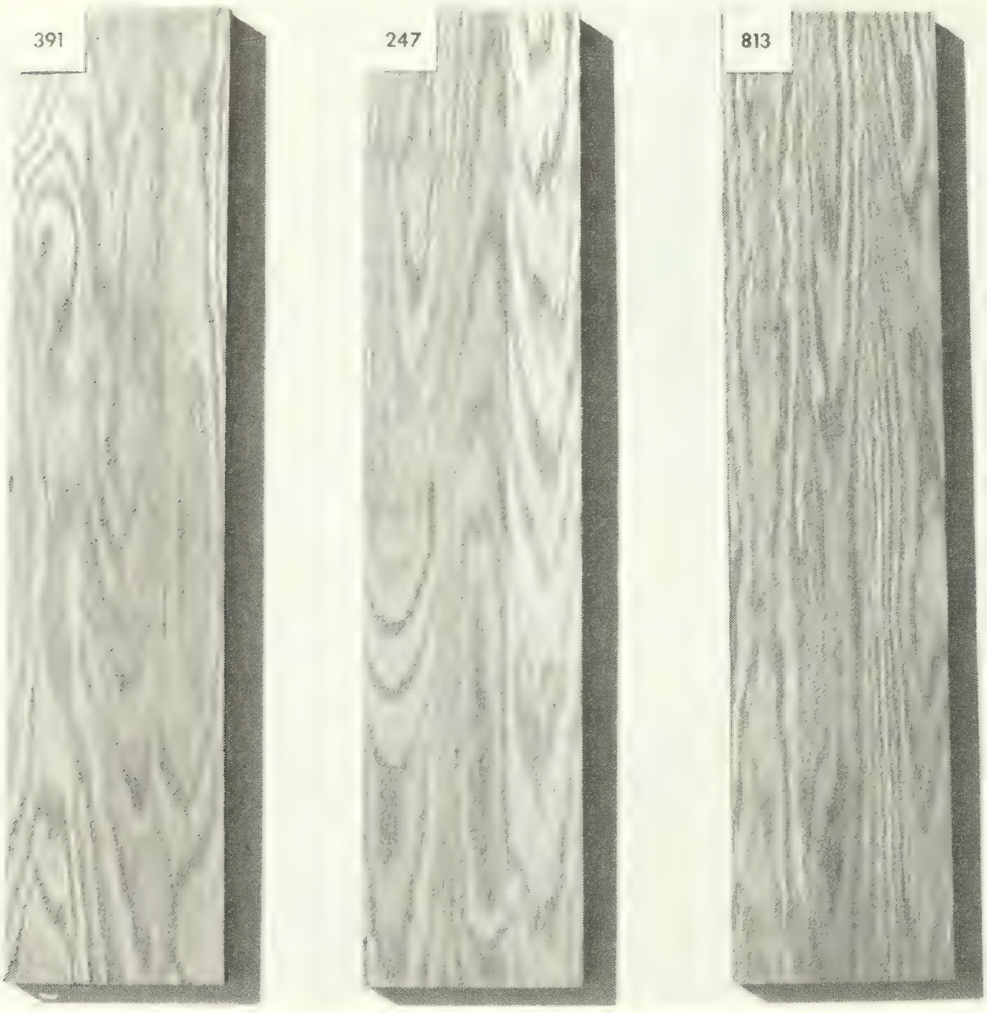
The observers were told:

> "Each display contains 3 panels. Two of the panels are made up of 4 pieces of wood. The other is made up of just 3 pieces. All pieces are the same width. You are to pick the 'odd' panel; that is, the one made up of just 3 pieces."

As can be noted from the instructions, focusing attention on the wood pieces caused observers to look for an end joint of some kind in two of the three panels.

The participants viewed each display from a distance of 5 feet. All were required to select one of the three panels in each display as the non-Sem panel—even if they were unable to perceive the difference between the odd and Sem panels. If none of the observers could detect this difference (identify the Sem joints), each panel would have an equal chance of being chosen. Thus, for each display, participants would have perceived the difference between non-Sem and Sem panels only if the odd panel were selected significantly more often than would be expected by chance alone (Fig. 2).

Figure 2.—The three-panel oak display. Can you identify the odd non-Sem panel?



Part II

In the second part of the test, we measured the sensitivity of perceptions of Sem joints. Could the degree of matching of grain and color around the joint alter perceptibility? We displayed two 39 x 10-inch panels (one oak and one cherry). We made a detailed presentation of what a Sem joint looked like, and gave each observer a sample piece with a Sem joint. Thirty-four of the 47 participants of Part I volunteered to take the second part of the test. We do not know why the others did not wish to continue, but it is possible that they became frustrated in failing to perceive the Sem joints.

To speed processing, the second group of observers was divided in half. One half was asked to locate the Sem joints in the oak panel; the other half was asked to locate the Sem joints in the cherry panel. Neither group was told that there were five joints in each panel, or that two joints were purposely made to be easily seen, two were made to be difficult to spot, and one was made so that the degree of visibility fell between these extremes.

Panel construction

In developing the test panels for Parts I and II, we chose close-grained (black cherry) and open-grained (northern red oak) pieces of No. 2 Common lumber, and we used clear finishes. All joints were the same size and shape. Factors considered were the Sem pattern, grain pattern, and finish.

Sem pattern. The end joint pattern was a sine wave with a 2½-inch amplitude (height) and a 5-inch period (width). With the precision machining possible with a numerically controlled router, glue lines .001 inch or less in thickness can be produced easily. From a distance of 4 to 5 feet, the actual glue line is not readily visible. What is observed are differences in the joined pieces.

Grain pattern. Hiding the Sem joint in edge-grained pieces is easily done. The use of Serpentine end matching to remove knots from edge-grained strips often results in a match of straight-grain patterns from the same strip. Our studies suggest that edge-grained joints are more easily detected when pieces with widely different growth patterns are joined.

Flat-grained material can be more difficult to match because the grain pattern appears to change continually along the length of the strip. Also, series of annual rings often "point" in opposite directions. For best grain matching, annual rings of the same size and shape should be joined. Because flat-grained pieces offer the widest range of differences in grain patterns and, therefore, in the degree of visibility of Sem joints, we used only flat-grained strips to strengthen the objectivity of the tests.

Finish. Finishing can be used to hide or obscure differences in joined pieces of wood panels. Multistep finishing—the use of combinations of bleach, dark stain, filler, sealer, and topcoat—minimize these differences. It is also possible to tone, highlight, or distress panels to draw attention from joined areas. However, we avoided such techniques in this study. We finished all panels by spraying them with a penetrating oil, a sealer, and a clear topcoat. These materials heightened the contrast between the earlywood and latewood in the annual rings, and made differences between pieces more obvious.

RESULTS

Part I

The results indicated that participants generally failed to detect the Sem joints in either display (Table 1). Chi-square tests revealed no significant differences between the number of times the non-Sem panels were selected and the number of these selections that could be attributed to chance. But in the oak display, one Sem panel (No. 247 in Fig. 2) was chosen significantly more often than the other panels. However, closer examination re-

Table 1.—The number of times each panel in the oak and cherry displays was selected as the non-Sem panel

Panel code and type	Number of times selected	Percent
OAK		
No. 813 Sem (4-piece)	11	23
No. 247 Sem (4-piece)	24*	51
No. 391 non-Sem (3-piece)	12	26
CHERRY		
No. 980 Sem (4-piece)	16	34
No. 154 Sem (4-piece)	18	38
No. 638 non-Sem (3-piece)	13	28

*Significant at 5 percent level.

vealed that the grain pattern in Panel 247 blended less well than that in the other panels.

Did this difference in panels bias our test for the oak group? We do not believe so, because it was not great enough to preclude other choices. In fact, we had not been aware of this rather subtle difference before examining the test results. Although a substantial number of participants used this difference as the basis for selecting the odd panel, they nevertheless failed to detect the Sem joint in Panel 247. Also, there was little difference in the number of correct choices in the oak and cherry displays. Yet all panels in the cherry display were chosen according to what was expected. So, in one sense, the similar number of correct choices in each display tends to support earlier indications that the Sem joints had not been detected.

Part II

The results conformed to what was expected. The most conspicuous joints in both the oak and cherry panels were identified most often, and the least conspicuous joints were identified least often (Table 2). Though the 17 people in each test group knew exactly what they were looking for, it was apparent that joint perception was difficult in many instances. For example, only one joint—a highly contrasting light-dark match in the oak panel—was found 100 percent of the time (Fig. 3). By contrast, three of the four inconspicuous joints went undetected about 66 percent of the time.

While the pattern of joint selection was similar for both the oak and cherry panels, the difference

Figure 3.—The nine-piece oak panel with five Sem joints. Can you locate all five joints? Two should be obvious.

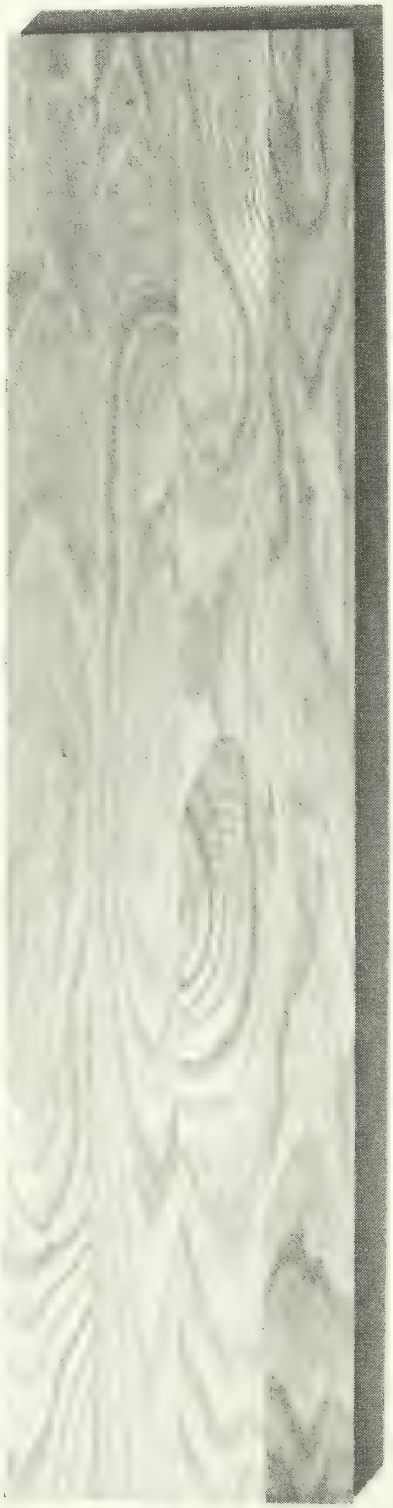


Table 2.—The number of times each Sem joint in the oak and cherry panels was identified

Joint no.	Degree of visibility	Number of times identified	Percent
	OAK		
1	Inconspicuous	5	29
2	Inconspicuous	8	47
3	In between	9	53
4	Conspicuous	16	94
5	Conspicuous	17	100
	CHERRY		
1	Inconspicuous	6	35
2	Inconspicuous	6	35
3	In between	10	59
4	Conspicuous	12	71
5	Conspicuous	12	71

between selections of the conspicuous and inconspicuous joints was greater for the oak than for the cherry panel. This was a result of the greater variation in grain and color in the oak lumber.

Only two participants in the cherry group correctly identified all five joints in the cherry panel; only one observer identified the five joints in the oak panel. The latter observer also identified two joints that did not exist, but this situation was not unusual; five observers in each group were deceived by characteristics of the wood itself.

CONCLUSION

We believe that we developed a strong test of Serpentine end matching. Except for preselecting the pieces to be joined, we did nothing to hide the joints, either by drawing attention from jointed areas or by altering the normal variation in grain and color around the joints. In fact, the finish of penetrating oil, sealer, and clear topcoat tended to accent the differences in grain and color. Also, all joints were the same size and shape. Thus, once one joint was detected, subsequent identifications were made easier.

The observers were knowledgeable in the properties of hardwood and furniture manufacture. Yet they generally failed to perceive the Sem joints in the test of gross perception. In each display, the non-Sem panel was chosen less often than could be attributed to chance. And while the test of sensitivity of perception suggests that oak may require greater attention than cherry when panel materials are matched, the less conspicuous joints were difficult to detect, even when observers were well-informed about Serpentine end matching.

We believe that joint perceptibility need not be of undue concern to the hardwood furniture industry in adopting Serpentine end matching. Given proper selection of pieces for matching and moderate finishing, the industry can produce joints that are as good as or better than the most inconspicuous joints in the test panels.

Additional information about Serpentine end matching can be obtained from the USDA Forest Service, Forestry Sciences Laboratory, Princeton, West Virginia 24740.

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- Warren, Pennsylvania.

PLASTIC TUBING AND MAPLE SYRUP QUALITY

by Russell S. Walters and Harry W. Yawney

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NORTHEASTERN FOREST EXPERIMENT STATION
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Abstract

Maple syrup made from sap collected using improperly or carelessly installed plastic pipelines varied more in color from day to day, and was more often darker in color, than sap collected from either the properly installed pipeline or clean, frequently emptied galvanized buckets. Use of both properly installed tubing and buckets, following recommended procedures, produced light colored syrup of equal quality throughout the entire maple syrup season.

IN RECENT YEARS, the use of plastic pipeline systems for collecting maple sap has increased.

Following the 1974 sap season, there were large inventories of the commercial grade (dark amber) of pure maple syrup. The lack of markets for it and the unstable, low prices had a tremendous effect on the maple syrup industry in both the United States and Canada.

It may be only coincidence, but the question must be asked: Was the surplus of dark syrup in any way a result of the greater use of plastic tubing?

To compare the quality of syrup made from sap collected by several different techniques, we recorded the greatest day-to-day variations in syrup color, and more often observed that dark colored syrup resulted when improperly or carelessly installed tubing was used. The other methods investigated were properly installed tubing, galvanized buckets with covers, and a special aseptic technique.

BACKGROUND

Characteristically, the maple syrups produced early in the season are light amber in color and delicately flavored. Usually darker syrups with stronger flavors are produced as the season progresses. The color of maple syrup is strongly associated with its quality, and this has become the most important criterion for grading it. Typically, the lighter syrups are for table use and are the highest grades.

After the 1974 season, the major users of the commercial grades of syrups did not buy the quantities they had formerly. Because of the magnitude of this problem, the Province of Quebec launched major promotional and financial programs to assist the Quebec industry. This marketing problem was also a major reason for the formation of the International Maple Syrup Institute to promote pure maple syrup products (Sipple 1975).

In recent years, syrup producers have found it more difficult to find labor for sap collecting, and have turned to plastic piping as an alternative. Not only does the pipeline system require less total labor, but it also allows for more efficient use of labor by spreading the workload over a longer period of time before and during the sap season (Huyler 1975). Huyler noted another reason for the increased use of plastic tubing: buckets cost more. As a result, many new operators start out with plastic tubing.

WHAT WE DID

During the 1975 and 1976 sap-flow seasons, we made daily collections of sap samples from 3 trees with sterilized taps and with standard bucket taps, and from 10 trees with plastic pipelines both correctly and poorly installed. The pipeline that was carelessly installed had sharp switchbacks that inhibited a steady sap flow and sags where sap would remain after a flow period ended (Fig 1).

In the 1975 season, the trees were tapped on 14 March. The sap collection began on 17 March and ended on 17 April 1975. Samples were collected on the 11 days that enough sap was produced for a 1- to 2-gallon sample.

The trees were tapped on 24 February for the 1976 season. Sap was collected from 5 March through 30 March 1976. Samples were taken on 9 days.

After each daily collection, the buckets and tanks were emptied, and sterilized jugs were attached to the sterile taps. If there were small "weeping" flows between major runs, this sap was discarded before the next flow. This ensured that each daily sample did not include any sap left over from the preceding day—a procedure recommended to syrup producers if high-quality syrup is to be produced consistently (Willits 1965).

Sap collection by an aseptic method was used to establish a standard for comparison with the other procedures. Before the taphole was drilled, the tree bark was scraped with a sterile chisel, saturated with alcohol, and ignited. As the alcohol burned, the hole was drilled with a sterilized bit, and a sterilized spout quickly inserted. The sap was collected in sterilized gallon jugs (Fig. 2). Each jug was fitted with a two-hole stopper. A glass U-tube, plugged with cotton at one end, was inserted in one hole to equalize the air pressure. A straight piece of glass tubing connected to a plastic tube and spout was inserted in the other. The entire apparatus was sterilized by alcohol dip before it was attached to the tree.

Two plastic pipelines were installed parallel to each other, each connecting one of two tapholes in each of 10 trees. Both lines collected sap from the

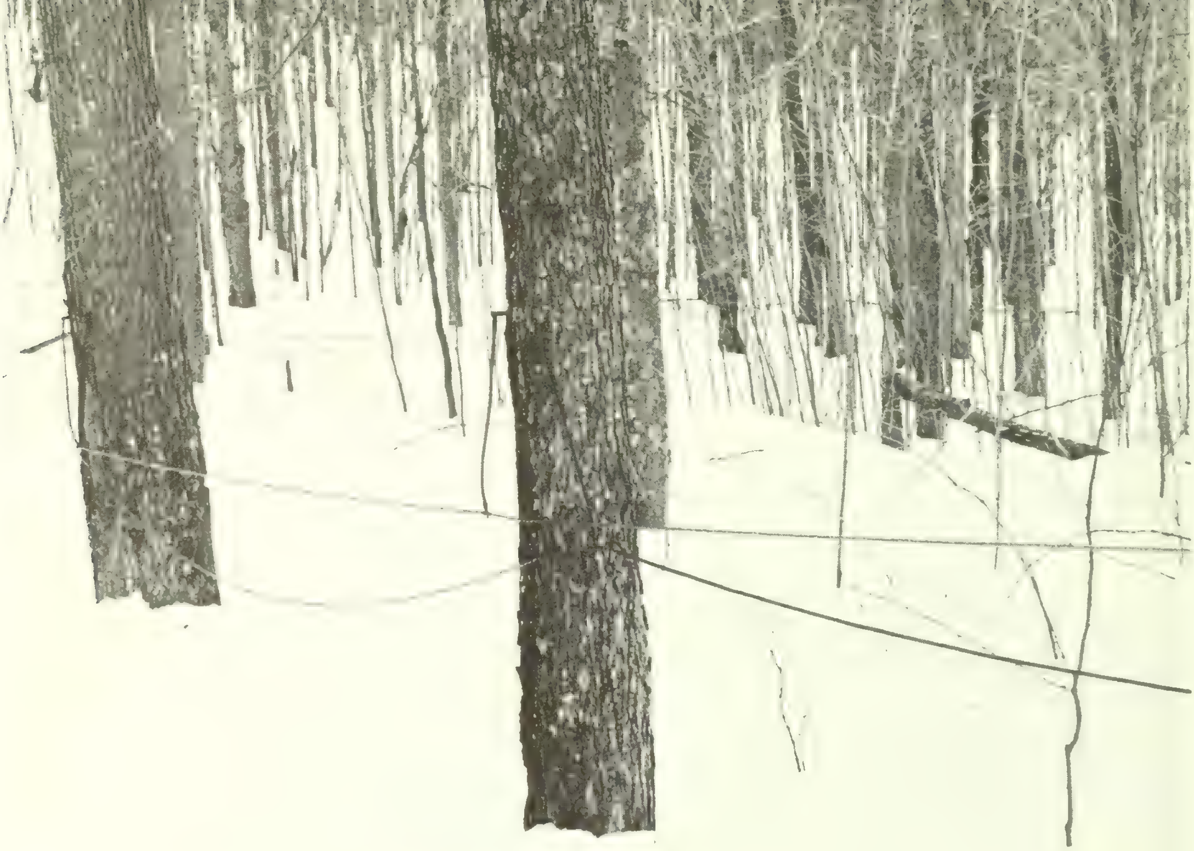
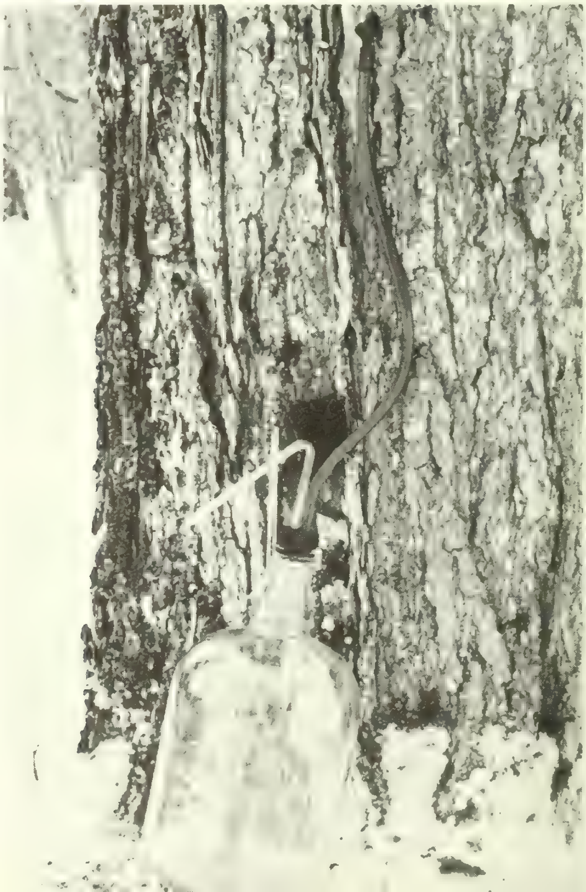


Figure 1.—Sap was collected by two parallel plastic pipelines. One was hung properly, while the other has sags and sharp switchbacks.

Figure 2.—Glass jug and apparatus for collecting maple sap under sterile conditions.



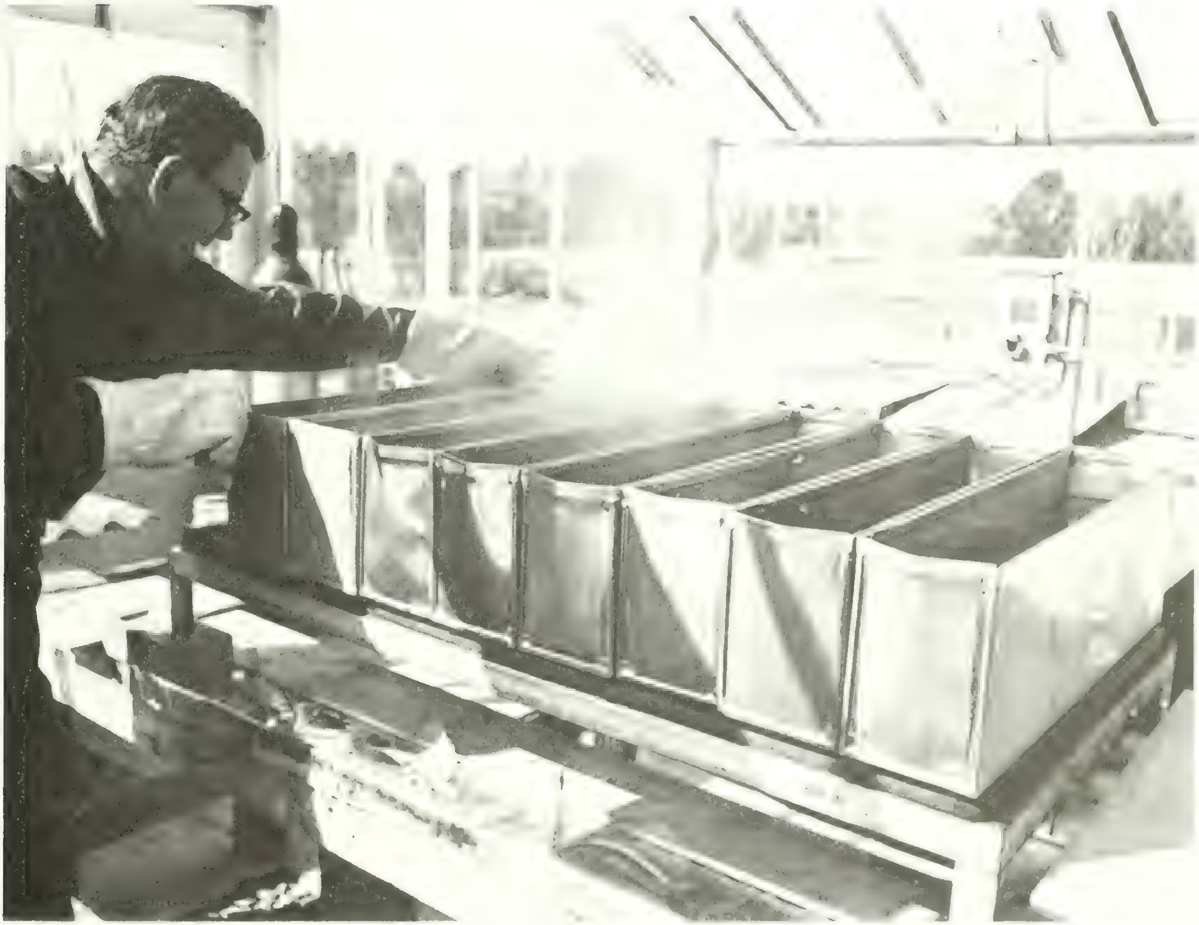
same trees. These lines extended for approximately 300 feet from the lowest taphole to the sap collection tank. One line was correctly installed without sags, sharp turns, or switchbacks, and good slope was maintained. The other line was carelessly connected in a deliberate attempt to simulate poor installation.

The sap collections were picked up and taken to the laboratory each afternoon and stored at approximately 2°C. The following morning each sample was subsampled and plated to determine bacteria and yeast counts. Plate counts were made in a manner similar to the standard methods used for dairy products (Am. Public Health Assoc. 1960). The remainder of each sample was then concentrated by boiling in an open stainless steel pan (Fig. 3) to standard density syrup which is 66.0 °Brix (at 20°C).

We graded the samples by comparing them with glass color standards for maple syrup that were developed by the U. S. Department of Agriculture (Brice and Turner 1956). The color intensity of each sample was also measured in the colorimeter at the recommended 560 nm. Light transmitted through undiluted syrup in a round, 1/2-inch cuvette was recorded as a percentage of the amount of light that would pass through distilled water (Brice and Turner 1956).

When maple trees come out of dormancy in the spring, physiological changes in the tree result in sap which lends syrup an unpleasant flavor. This is called "buddy" syrup because it is most noticeable in sap from trees whose buds have swelled or burst. We tested each syrup sample for buddy flavor by using the ninhydrin-reagent method (Underwood 1963). All of the syrup made from sap

Figure 3.—Each sap sample was concentrated by boiling in a separate open stainless steel pan.



collected after 18 April 1975 and 31 March 1976 developed a violet color in the test, which indicates buddy flavor. The samples collected after those dates were discarded because their off flavor make them unacceptable as table syrup. Data on these samples are omitted.

RESULTS AND DISCUSSION

We found that light colored syrup was produced from all sap collections during the entire 1975 season when the sap was collected by buckets or properly installed tubing (Fig. 4). Only at the end of the season, just before the development of buddy flavor, did the color grade change from light amber to medium amber, the accepted minimum for table use. Every sap collection from the sterile tap produced light amber syrup. On the other hand, the syrup made from sap collected by the poorly installed tubing varied greatly from dark to light during the season. Twice, the poor tubing resulted in syrup so dark that it graded below medium amber. One of these dark samples was collected from the first sap run of the season, and graded substandard.

Figure 5 shows that sap collections from poor tubing produced darker syrup on 3 days in 1975, when the other collection systems produced light amber syrup. One day was the first sap flow of the season, 17 March, and the other two days, 2 and 12 April, were preceded by a period without a sap flow. A possible explanation for the dark color is that sap accumulated in the sagging portions of the pipeline and fermented; when a sap flow be-

Figure 4.—Maple syrup samples from the 1975 seasons showing color comparisons among daily sap samples from four different sap-collecting methods. The collection date is shown at the bottom.

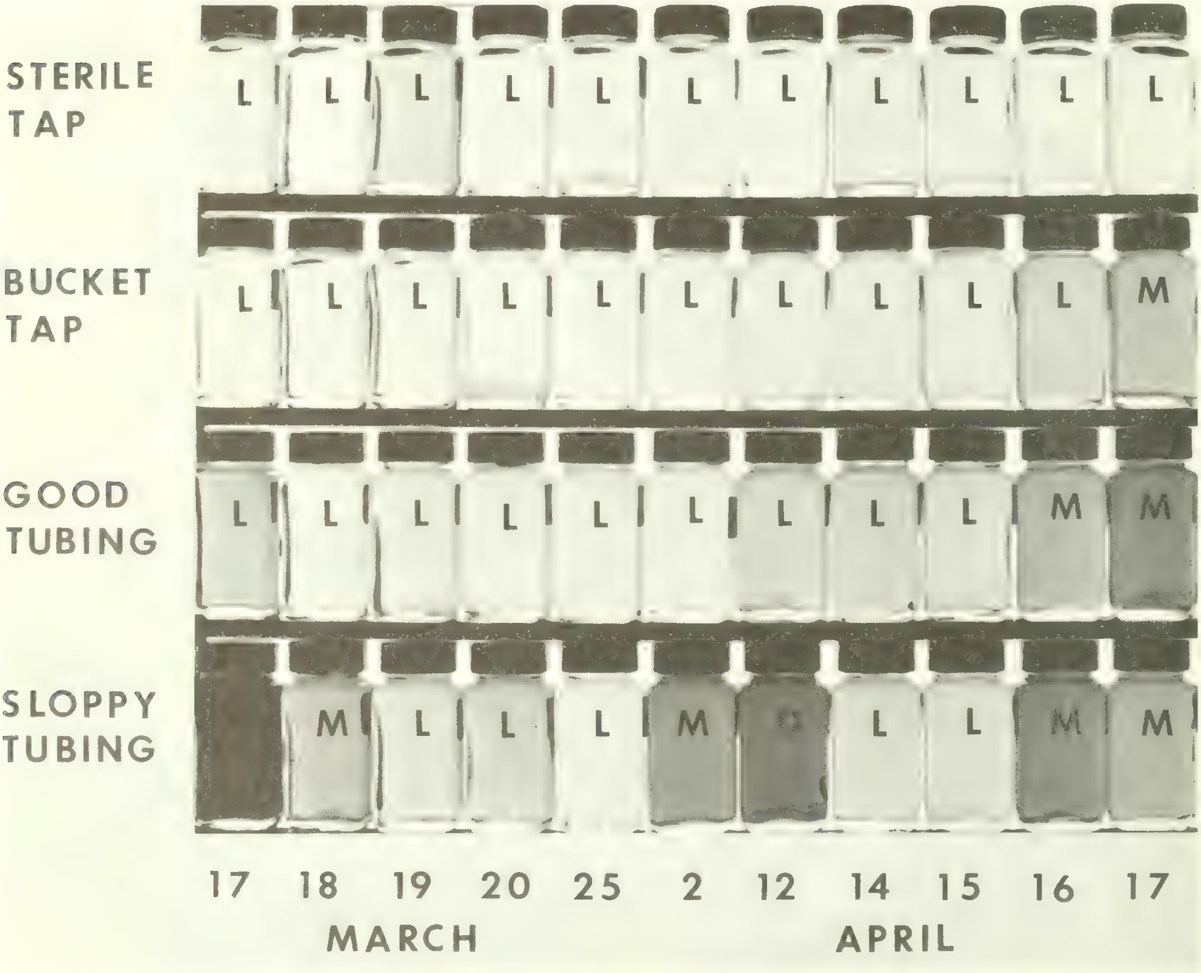
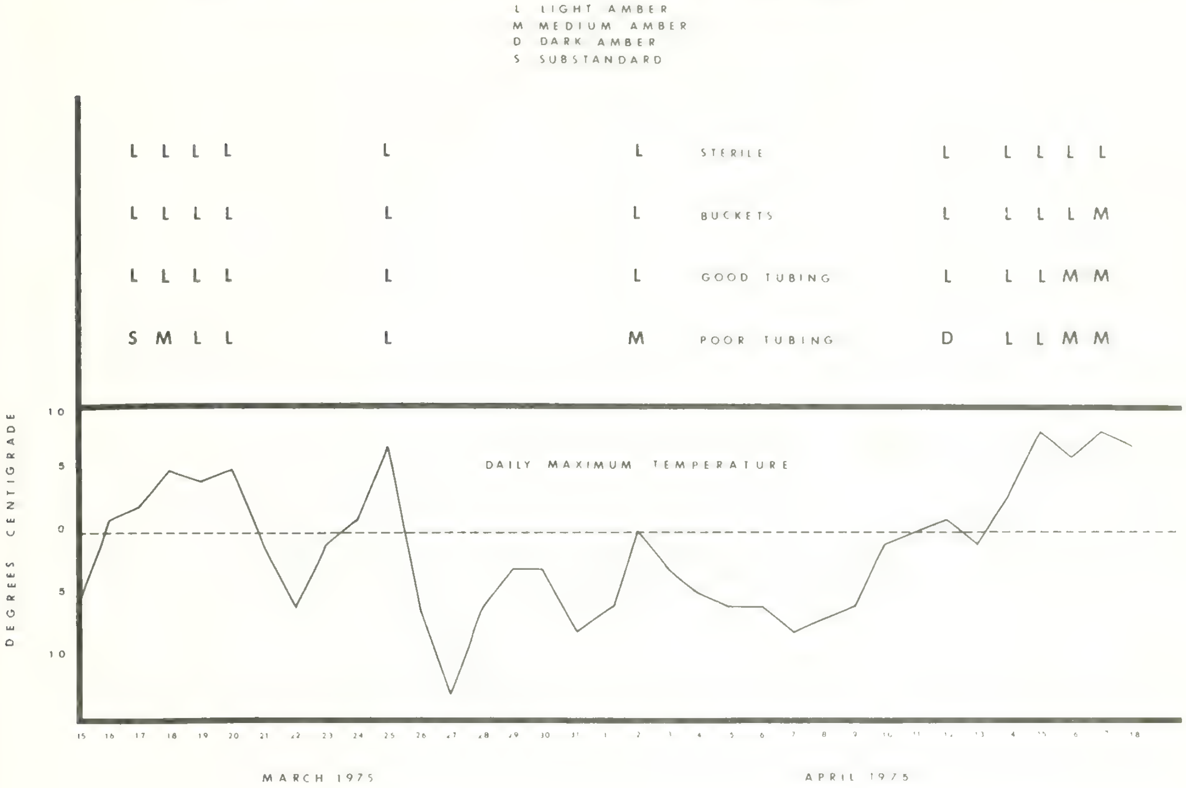


Figure 5.—Maple syrup colors on the day of sap collection, and daily maximum temperatures for the 1975 season.



gan, the fermented sap contaminated the new collection. Fermentation can result in dark colored syrup (Naghski et al. 1957).

A general trend toward a darker syrup color was indicated by lower light transmittance readings as the sap season progressed (Fig. 6). The light transmittance of samples from the buckets and good tubing collections followed a similar pattern: high readings until just before the development of buddy flavor, when both dropped. Readings for the poor tubing varied from high to low throughout the season, while the sterile tap readings remained high (light amber grade) even throughout the buddy sap period.

As the sap season progressed, there was also a trend toward increased quantities of bacteria and yeast in the sap. This trend seems to be associated with the trend toward darker syrup color, and we might assume that increases in microbe population affect syrup color. But we were dealing with total bacteria counts, and made no attempt to isolate or identify specific organisms. Some bacteria affect syrup flavor, others syrup color, and still others apparently do not affect either (Edson et al. 1912). Standard plate counts may be misleading as to the effect of bacteria on syrup quality. We did not find a good correlation between large populations of bacteria in the sap and syrup color. Sometimes bacteria colonies were found in the aseptically collected sap, although considerably less numbers than in the sap collected by other methods. On the other hand, some of the sap collected by the bucket or tube contained high bacteria counts, yet produced very light syrup.

Data from our microbe count suggest that the presence of yeast in sap is more directly related to syrup color than the bacteria populations, and is perhaps even more important. Syrup color darkened or lightened as yeast numbers increased or decreased (Table 1). No yeast populations were found in sap samples from the sterile taphole, and these samples were very light colored during the entire season.

Our observations of the relationship between sap contaminated by yeast and syrup color and flavor is consistent with the literature. Dark color

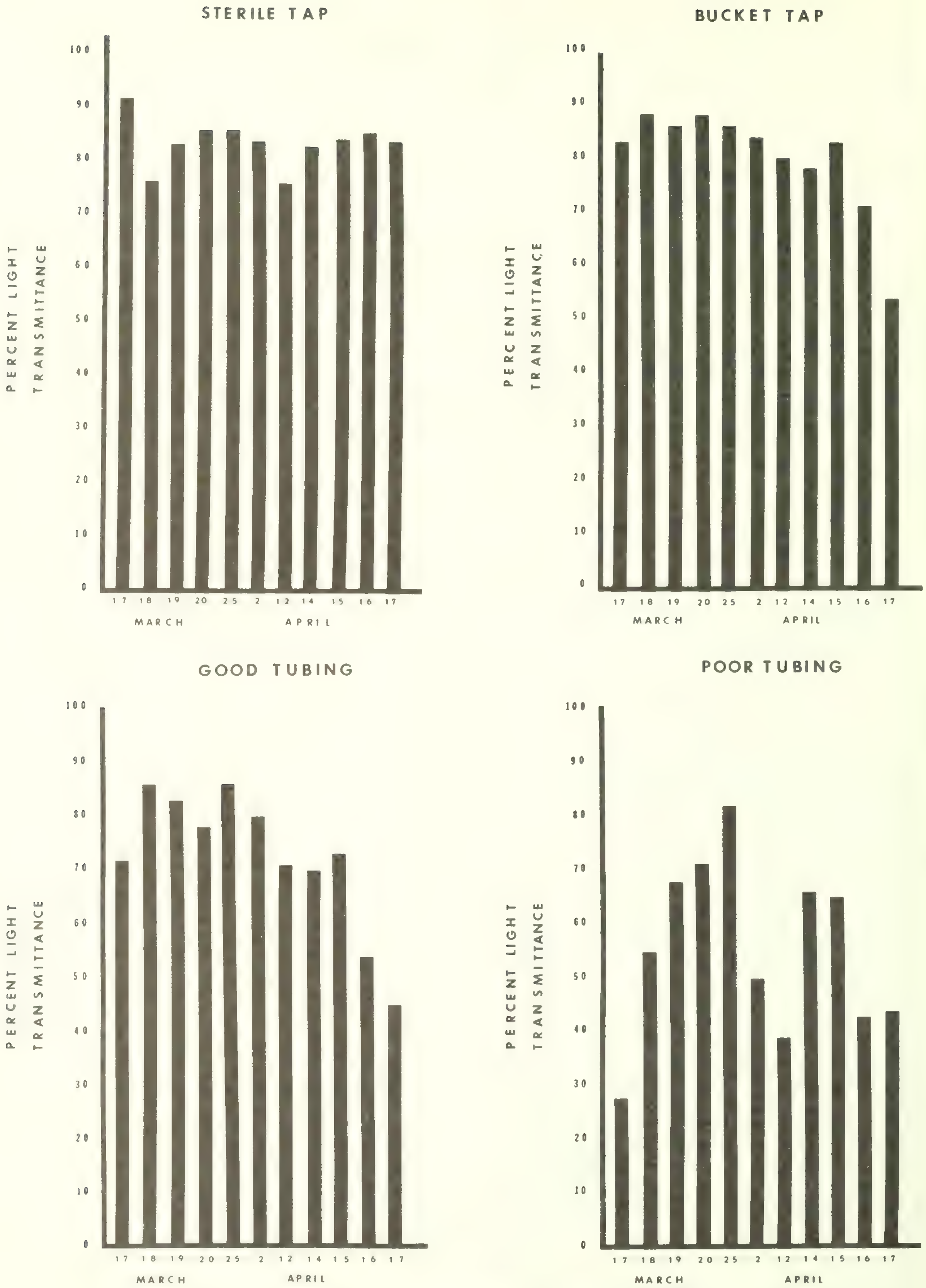


Figure 6.—Percent light transmittance at wavelength 560 nm through daily syrup samples from four different sap collection methods.

Table 1.—Standard plate counts of bacteria and yeast from sap collected by four methods (1975)

	Good tubing		Poor tubing		Buckets		Sterile	
Date	Bacteria	Yeast	Bacteria	Yeast	Bacteria	Yeast	Bacteria	Yeast
March 17	5,000	0	34,000	1,000	9,000	0	12,000	0
March 18	1,000	0	10,000	0	22,000	0	13,000	0
March 19	2,000	0	1,985,000	1,600	2,000	0	3,000	0
March 20	19,000	0	1,365,000	500	10,000	0	1,000	0
March 25	50,000	0	59,000	0	2,000	0	2,000	0
April 2	1,270,000	7,200	3,360,000	1,100	3,000	4,900	0	0
April 12[a]	—	—	—	—	—	—	—	—
April 14[a]	—	—	—	—	—	—	—	—
April 15	277,000	400	258,000	1,300	14,000	300	1,000	0
April 16	465,000	1,400	11,200,000	3,500	2,320,000	2,900	2,000	0
April 17	3,450,000	10,800	—[b]	18,400	1,026,000	42,000	1,000	0

[a] Data lost.
[b] Too numerous to count.

Table 2.—Standard plate counts of bacteria and yeast from sap collected by four methods (1976)

	Good tubing		Poor tubing		Buckets		Sterile	
Date	Bacteria	Yeast	Bacteria	Yeast	Bacteria	Yeast	Bacteria	Yeast
March 5	58,000	0	26,000	1,500	48,000	700	53,000	0
March 6	60,000	0	17,000	2,000	40,000	500	3,000	0
March 15	0	0	74,000	31,100	20,000	14,200	0	0
March 20	10,000	0	13,000	14,900	90,000	8,800	20,000	0
March 21	10,000	0	410,000	13,500	490,000	1,100	3,000	0
March 24	2,000	0	209,000	16,200	80,000	4,800	18,000	0
March 26	2,000	0	300,000	14,400	1,460,000	4,300	2,000	0
March 29	69,000	0	2,180,000	4,200	3,070,000	4,800	0	0
March 30	50,000	0	780,000	300	309,000	9,800	167,000	0

and caramel flavor are strongly influenced by the presence of invert sugars (Naghski et al. 1957). Invert sugars—glucose and fructose—are formed from sucrose (the only sugar in fresh sap) by hydrolytic action of invertase. Fermentation caused by the growth of yeast in the sap is a main source of invertase (Morrisson and Boyd 1966). In our opinion, the length and temperature of sap storage before processing influence fermentation. Invert sugars may not develop in sap containing many yeast spores if the sap is processed promptly. As storage time increases, the amount of fermentation increases.

The results shown by the data collected during the 1976 season (Table 2 and Fig. 7) generally agree with and follow the same trends observed in the 1975 data. The 1976 trends are not as well defined. This is most probably due to the peculiarities of the season.

The 1976 season started unusually early, and was terminated by the very early development of buddy sap. Sap was first collected on 5 March, as compared to 17 March 1975. The sap became buddy after 18 April in 1975, but buddiness was evident by 31 March in 1976—nearly 3 weeks earlier. On 5 March (the date of the first 1976 sap run), the maximum temperature was 14°C. The temperature did not go that high during the entire 1975 season. In addition, the last 2 weeks of March 1976 were characterized by very warm tem-

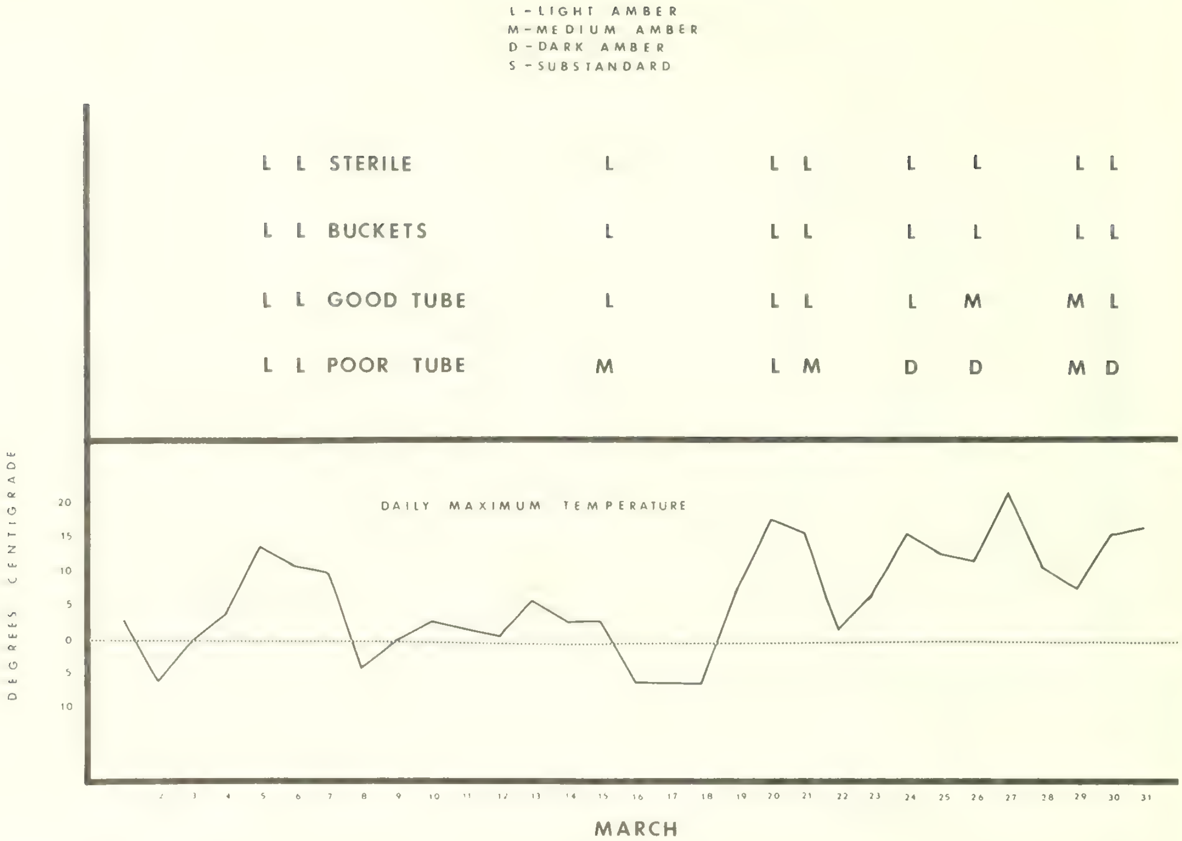


Figure 7.—Maple syrup colors on the day of sap collection and daily maximum temperatures for the 1976 season.

peratures, which reached as high as 20°C. (Fig. 7). High temperatures during these 2 weeks no doubt contributed greatly to the early development of buddy sap.

SUMMARY AND RECOMMENDATIONS

We found that maple syrup color differed very little whether it was made from sap collected by a properly installed pipeline or by frequently emptied, clean, galvanized buckets with covers. However, sap collected by a poorly installed plastic pipeline produced syrup that varied widely in color from day to day during the season. Our collections from sterilized tapholes and apparatus demonstrated that it is possible to produce light colored syrup during the entire season, even from buddy sap.

We have shown that a satisfactory grade of maple syrup can be produced using the plastic pipeline for sap collection. But, it is extremely important that the line is installed without sags and low points, and that it has adequate slope for complete drainage. Our results further indicate the need to sanitize the sap-collection equipment at the beginning of the season, and to keep the equipment clean throughout the season.

Finally, we concluded that the variation in the color of syrup from sap run to sap run was most likely caused by sap that fermented because it was trapped in a poorly installed pipeline or left in buckets. Buckets should be emptied after runs that are too short to warrant collection (even though this is time-consuming and expensive). Failure to install lines properly, keep buckets clean, and process sap promptly could cause the syrup to be dark, perhaps off-flavor, and of a lower grade.

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- Warren, Pennsylvania.

by David A. Gansner
Owen W. Herrick
William B. White

Economic Analysis of the Gypsy Moth Problem in the Northeast

IV. Forest Stand Hazard Ratings For Gypsy Moth

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Abstract

Provides a practical method for rating the potential hazard of impending gypsy moth attacks to forest stands. Stepwise multiple regression analysis is used to develop equations for estimating tree mortality from easy-to-measure key characteristics of stand condition.

This is part of the series of publications on the economic impact of the gypsy moth.

THE GYPSY MOTH, *Lymantria dispar* (L.) [1] is still going strong. During 1977 it defoliated 1.6 million acres of forest land. Half of the defoliation was severe and most of it occurred in Pennsylvania.

Decisions about controlling the gypsy moth are being made every year. They are often based on intuition alone because there are no reliable and practical means for predicting and evaluating impacts of the insect. In working toward a solution to this problem, we have developed models for rating the potential hazard of impending gypsy moth attacks to forest stands—simple equations that predict tree mortality in terms of easy-to-measure key characteristics of stand condition.

APPROACH

Underlying the development of the hazard rating equations is the premise that tree mortality caused by the gypsy moth in any particular forest stand is related to and can therefore be expressed as a function of selected characteristics of that stand's condition. Stepwise multiple regression analysis was used to develop equations for estimating tree mortality as a function of stand characteristics.

Data used for the analysis were collected from 1/10-acre sample field plots in Pike and Monroe Counties, Pennsylvania. This area was the frontier of gypsy moth infestation in 1970. The information came from 143 plots that remained untreated throughout the 1970-76 study period. Only trees 3 inches dbh and larger were considered. Cumulative tree mortality on the sample plots ranged from 0 to 67 percent and averaged 13 percent. Volume loss ranged from 0 to 26.6 cords per acre and averaged 2.5 cords. Value loss ranged from $0 to $468 per acre and averaged $14.

Dependent variables

Two dependent variables were analyzed to rate forest stands for tree mortality caused by gypsy moth:

- Number of trees per acre that died during the study period
- Percentage of trees that died during the study period

Independent variables

A variety of forest stand characteristics assumed to be good predictors of tree loss were selected for analysis. They are measures of:

Stand-size composition
Species composition
Average tree diameter
Timber stocking
Stand age
Crown position
Crown condition
Site index
Land capability
Elevation

---

[1] Lepidoptera: Lymantriidae

Aspect
Slope
Positon on slope

The choice of these variables was based primarily on findings of Kegg (1971), Campbell and Sloan (1977) Houston and Valentine (1977) and our own work (Herrick et al. 1978).

Data for these variables provided input for development of the hazard rating equations.

RESULTS

Stepwise multiple regression analyses gave us two simple equations for rating the hazard (HR) of impending gypsy moth attacks to forest stands:

$$HRN = 11.85 + 0.82\,(NPC) + 0.0005\,(NWO)^2 \qquad R^2 = 0.73$$

$$HRP = 4.16 + 0.83\,(PPC) + 0.001\,(PWO)^2 \qquad R^2 = 0.57$$

where HRN = Number of trees per acre that will die

HRP = Percentage of trees that will die
NPC = Number of live trees per acre with poor crowns[2]
NWO = Number of live trees per acre in the white oak species group
PPC = Percentage of live trees with poor crowns
PWO = Percentage of live trees in the white oak species group

Only two of the many elements of stand condition analyzed as independent variables are included in these equations and their inclusion makes good sense. *White oaks* are a preferred food of the gypsy moth and are usually attacked more severely than other tree species. Trees with *poor crowns* have low vigor and are more likely to die after defoliation.

The coefficient of multiple determination (R^2) for each equation is greater than 0.57. Thus the relatively small number of independent variables included in these equations explain a rather large share of the variation in tree mortality for the sample plots; the models fit the sample data rather well.

A CHECK ON PERFORMANCE

Does it work? This is the real measure of any predictive model's worth. Plans have been made by Northeastern Area State and Private Forestry's Forest Insect and Disease Management staff of the U.S. Forest Service to test and improve this and other systems for predicting and evaluating impacts of the gypsy moth. The tests are planned for forest stands in Pennsylvania, West Virginia and Maryland in advance of gypsy moth outbreaks.

We checked the performance of the hazard rating equations by applying them to the 143 sample plots used in this study. Tree loss estimated by the equations was compared with actual loss recorded on the plots. Each plot was assigned hazard ratings based on predicted estimates of tree loss as follows:

Tree mortality measure	Hazard rating class		
	Low	Moderate	High
Number per acre	<30	30–74.99	75+
Percent	<10	10–24.99	25+

Then, hazard ratings predicted by the equations were compared with actual ratings recorded for the plots. The percentage of plots in each rating category was:

Hazard rating predicted by equations	Actual hazard rating of plots					
	Trees per acre			Percent of trees		
	Low	Moderate	High	Low	Moderate	High
Low	72	24	4	76	21	3
Moderate	10	77	13	24	63	13
High	5	17	78	0	23	77

---

[2] The "poor" crown condition class was assigned to trees with: crowns consisting of 50 percent or more dead branches (allowances permitted for non self-pruning species); foilage density, size, and coloration of definite subnormal quality; or heavy epicormic sprouting.

Three-fourths of the ratings predicted for the plots agreed with actual outcomes. Very few of the predictions missed by more than one rating class. For example, less than 4 percent of the plots classified as low hazard actually turned out to be in high hazard situations.

This exercise by no means represents an exhaustive test of model performance, but it does indicate the kind of results that users of the hazard rating equations might expect.

SUMMARY

People who have to make decisions about controlling the gypsy moth need help with predicting and evaluating impacts of the insect. In response to this need, we have developed simple equations for rating the potential hazard of impending gypsy moth attacks to forest stands. The equations estimate expected tree mortality in terms of two easy-to-measure key elements of forest stand condition.

The models have some deficiencies. To begin with, they haven't been tested in the field, so we don't really know how well they work on new frontiers of infestation. Plans have been made to test them. Also, they take no account of important nontimber impacts such as the nuisance of caterpillars in recreation areas and back yards or the degrading effects of defoliation on environmental quality. And, while the analysis uses data that spans 6 years since outbreak, we can't be sure that all tree losses associated with the insect have yet accumulated.

But with all their faults, the models can provide useful tools for more effective gypsy moth control, particularly in situations where tree losses are considered important. We feel they can add a bit more objectivity to the process of making control decisions.

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- Beltsville, Maryland.
- Berea, Kentucky, in cooperation with Berea College.
- Burlington, Vermont, in cooperation with the University of Vermont.
- Delaware, Ohio.
- Durham, New Hampshire, in cooperation with the University of New Hampshire.
- Hamden, Connecticut, in cooperation with Yale University.
- Kingston, Pennsylvania.
- Morgantown, West Virginia, in cooperation with West Virginia University, Morgantown.
- Orono, Maine, in cooperation with the University of Maine, Orono.
- Parsons, West Virginia.
- Pennington, New Jersey.
- Princeton, West Virginia.
- Syracuse, New York, in cooperation with the State University of New York College of Environmental Sciences and Forestry at Syracuse University, Syracuse.
- Warren, Pennsylvania.